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WEAPONS ACTIVITIES
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LOS ALAMOS SCIENTIFIC LABORATORY
PART I (U)

by

Samuel Glasstone

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For a specified shape and composition, the size of a critical system can be decreased by surrounding it with a material which scatters neutrons back into the fissile core. By reducing the number of neutrons that escape, a smaller size (or mass) can become critical. Such a scattering material, on account of its function, is referred to, in general, as a reflector. In nuclear weapons it is called a tamper, because, in addition to decreasing the loss of neutrons by escape, it delays expansion of the exploding mass and permits a higher yield from the system undergoing fission, as will be seen later.

As is to be expected, increasing the thickness of the tamper decreases the escape of neutrons and thus makes possible a smaller critical mass of the fissile (or core) material. However, it has been shown by theoretical calculations, and verified experimentally, that when the tamper thickness reaches a certain value there is little more to be gained by a further increase of thickness (Fig. 1.2). Thus, when the thickness is about two to three neutron mean free paths in the given tamper material, its effectiveness in reducing neutron losses is within 10 per cent or so of an infinitely thick tamper.

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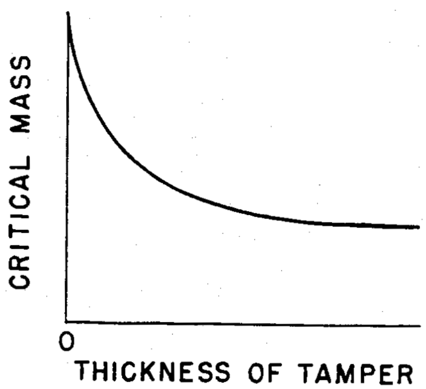

Fig. 1.2

Under precisely specified conditions, and for a given fissile (core) material, there is a definite mass that will be just critical. This is called a "crit." The critical masses of spheres of uranium-235 (94 per cent purity) and of plutonium-239 (97 per cent purity) are given in Table 1.3. In the first column are the values for a bare (untamped) sphere, whereas the values in the second column are for a thick (infinite) tamper of natural uranium metal. The effect of the tamper in reducing the critical mass of the core is very striking.

Table 1.3 Critical Masses of Spheres

Fissile Material	Bare	Tamped
Uranium-235	52 kg	17.2 kg
Plutonium-239	16 kg	5.8 kg

It may be noted that there is still another factor which affects the critical size: it is the speed (or energy) of the neutrons causing fission. The rate of the fission process is determined by the fission cross section, as will be seen later, and this varies with the neutron energy. However, as far as nuclear fission weapons are concerned, it may be tacitly assumed that only fast

neutrons, mainly with energies in the range from 0.5 to 2 Mev, are involved. Because of the relatively long slowing-down time, fission by slow neutrons would be less effective in an explosion.

1.3 Attainment of Criticality

Assembly Method (Gun-Type Weapons)

As long as a mass of fissile material is less than the critical value, i.e., it is subcritical for the existing conditions, there is no danger of a chain reaction occurring. But, if energy is to be released, e.g., in an explosion, the system must become critical and, in fact, highly supercritical, as will be seen shortly. There are two general ways, utilized in weapons, for rapidly converting a subcritical system of fissile material into one that is supercritical.

The first may be referred to as the method of assembly. Two portions of subcritical size are brought together very rapidly, so that the combined mass is supercritical. If a burst of neutrons is then introduced, a divergent fission chain will be initiated and there will be a rapid release of energy within a very short time. This is the principle used in weapons of the gun type: one subcritical portion of fissile material is shot into another subcritical portion, the combination exceeding the critical mass.

Compression Method (Implosion Weapons)

The second method of attaining criticality (or supercriticality) is based on compression of the subcritical fissile material. An approximate quantitative treatment of the relationship between the compression ratio and critical mass may be derived as follows. In accordance with the definition given above, the mean free path of a neutron is the average (crow-flight) distance a neutron travels before it interacts with a nucleus. The proportion of neutrons avoiding interaction, and which can consequently escape from the system, will evidently depend on the ratio of the dimensions, e.g., the radius of a sphere, to the mean free path. It is to be expected, therefore, that for a given fissile (core) material, under specified conditions, the critical radius will be approximately proportional to the neutron mean free path; thus, if R_c is the critical radius and λ_c is the mean free path in the core,

$$R_c \propto \lambda_c. \qquad (1.3)$$

The mean free path of a neutron is obviously inversely related to the probability of its interaction; the greater the probability of interaction, the smaller the distance the neutron will travel before it interacts with a nucleus. The probability of interaction is proportional to the number of fissile nuclei per unit volume, and hence to the density; so that, if ρ_c is the density of the core material,

$$\lambda_c \propto \frac{1}{\rho_c}. \tag{1.4}$$

The density of the material is dependent on the compression; thus, if C is the compression ratio, i.e., the volume before compression to that after,

$$C \propto \rho_c. \tag{1.5}$$

Combination of equations (1.3), (1.4), and (1.5) then leads to the result

$$R_c \propto \frac{1}{C}. \tag{1.6}$$

The critical mass M_c is related to the critical radius and the density of the material by

$$M_c = \frac{4}{3}\pi R_c^{\,3}\,\rho_c, \tag{1.7}$$

and upon substituting equation (1.6) for R_c and equation (1.5) for ρ_c, it is seen that

$$M_c \propto \frac{1}{C^2}. \tag{1.8}$$

The critical mass of a given fissile material is thus inversely proportional to the square of the compression ratio. By increasing the compression the critical mass is consequently decreased.

It follows, therefore, that if a subcritical mass of fissile material is compressed it may become supercritical. [redacted] In other words, it will be highly supercritical, and the introduction of neutrons will cause a rapidly divergent fission chain to develop.

DO (b)

If the mass of fissile (core) material is tamped, then the result in equation (1.8) is true only if both the tamper and the core are compressed to the same extent. Actually, uniform compression is not attained throughout; it is greater near the center of the bomb, i.e., in the core, than further out, e.g., in the tamper. Even within the core itself there is a compression gradient. In general, therefore, the relationship between the critical mass and the average compression ratios of the core (C_c) and of the tamper (C_t) may be represented by

$$M_c \propto \frac{1}{C_c^{\,1.2}} \cdot \frac{1}{C_t^{\,0.8}}, \tag{1.9}$$

so that when C_c and C_t are identical, this reduces to equation (1.8). For most cases of interes in the weapons field, a good approximation is

$$M_c \propto \frac{1}{C_c^{1.7}} , \tag{1.10}$$

since the conditions are such that the tamper is compressed to a smaller extent than is the cor

The use of compression to attain supercriticality is employed in weapons of the implosion type; the reason for this name will be seen later. Not only does increased compression result in a decrease in critical mass, it is also accompanied by an increase in efficiency of the energy release, as will be seen in Section 2.1. Consequently, the attainment of higher and higher compressions is one of the important objectives of weapon development.

1.4 Neutron Multiplication

Rate of Fission Reaction

No matter how it originates, an explosion involves the very rapid liberation of a large amount of energy. If the energy is to be produced by fission, then the necessary condition is a very high neutron density, since the rate of fission, and, hence, the rate of energy release, is proportional to the number of neutrons per unit volume. It is of interest, therefore, to investigate the circumstances which lead to a high neutron density.

It was seen earlier that the number of neutrons available to cause fission, for every neutron captured in a fission process, in each generation is equal to k, i.e., to $\nu - \ell$, where ν is the average number of neutrons produced per fission and ℓ is the average number lost by escape and nonfission capture. This means that for every n neutrons present at the beginning of a generation, there will be nk present at the end, so that the gain of neutrons is n(k - 1) per generation. The rate of gain, dn/dt, may then be obtained, roughly, upon dividing the actua gain by the average time, τ, between successive fission generations; hence,

$$\frac{dn}{dt} = \frac{n(k-1)}{\tau}. \tag{1.11}$$

This result will be strictly correct only if the delayed neutrons play no significant part in maintaining the fission chain. As seen above, this condition is applicable to nuclear fission weapons.

The quantity k - 1, which is the excess number of available neutrons per fission, may be

Chapter 2

Efficiency of Fission Weapons

2.1 Determination of Efficiency

Definition of Efficiency

The efficiency (ϕ) of any weapon may be defined as the ratio of the energy actually developed when it explodes, i.e., the energy yield, to the total energy available, i.e.,

$$\phi = \frac{\text{energy yield}}{\text{energy available}} \tag{2.1}$$

In other words, it is the fraction of the energy available which is actually released in the explosion. In the case of a fission weapon this is equal to the ratio of the number of nuclei which actually undergo fission to the total number of fissile nuclei present.

In designing a fission weapon it is essential to be able to estimate its yield from theoretical considerations. But the calculation of the efficiency is very complicated, involving a detailed hydrodynamic treatment of the core material and tamper during the main period of energy release, i.e., in the interval between about the 50th and 55th generations after initiation of the fission chain. With the availability of high-speed electronic computers, such as the IBM 701 and the MANIAC, progress is now being made in the rapid calculation of the efficiency of any proposed fission weapon. However, the procedures are tedious and not necessarily complete, so that other, partially empirical, methods for determining efficiencies are still in general use.

Detailed Calculation Procedure

The following description is intended as a brief outline of the detailed method for calculating weapon yields (or efficiencies); its purpose is merely to give a general indication of the procedure used. The bomb assembly is divided, somewhat arbitrarily, into a finite number of concentric shells, and the time behavior of each shell, or "mass point," is determined by numerical calculations using equations describing the processes of neutron production, material acceleration, and heat flow. The initial time for purposes of these calculations, at which significant physical effects may be assumed to begin, is taken as that after the 50th generation. Up to this time the mass points are essentially stationary, and very little energy has been liberated. The subsequent changes with time, as the system expands, are treated by calculating the neutron density, position, and physical properties of the mass points at time $t + \Delta t$ in terms of those existing at time t. For convenience, different time intervals Δt may be taken for different purposes.

Starting with the initial radii, masses, and nature of the fissile material for the several mass points, the values of α and of the neutron distribution at the zero time can be determined

by some form of neutron transport theory. Then, making use of this alpha and the familiar equation (1.16), for the time rate of increase of neutron population, the neutron distribution after the interval Δt can be evaluated.

The next step is to determine the acceleration of the mass points by hydrodynamic calculations; this gives the velocity at Δt, from which the new radii of the mass points can be obtained. Finally, the temperature distribution is calculated from the heat flow equation, taking into account the energy produced by fission, the work done by the mass points in their outward motion, and the transfer of energy by radiation.

These calculations complete one cycle, since the new neutron densities, radii, and temperatures of the mass points are now known. From the temperatures, the new physical properties are determined. The whole procedure, starting with alpha and the neutron distribution, is repeated over and over until the bomb has completely exploded and the rate of energy release by fission has fallen almost to zero. Upon summing the number of fissions which have taken place, the total energy yield can be obtained. This includes the energy released by fission after the system has expanded and become subcritical. Although chain propagation is no longer possible, interaction of the many neutrons and fissile nuclei still present will result in a considerable energy production; this may amount to some 30 per cent of the total yield.

The Bethe-Feynman Formula

The formula for the efficiency of a nuclear explosion derived by Bethe and Feynman is admittedly approximate since it involves a number of simplifying assumptions. It is based largely on the following arguments. As a result of the energy liberated in fission, very large pressures are developed in the core, and the core-tamper interface consequently receives a large outward acceleration. This causes highly compressed tamper material to pile up just ahead of the expanding interface, in an effect referred to as the "snowplow" phenomenon, because of its similarity to the piling up of snow in front of a snowplow. The inertia of the compressed tamper will delay expansion of the core, so that a considerable pressure gradient will build up from the center of the core to its outer surface.

Further, as a result of the delayed expansion, it may be supposed that the volume of compressed core remains essentially constant during the first 50 or so generations following initiation of the fission chain. After this interval, almost the whole of the bomb energy is released within an extremely short period, during which time the core expands rapidly until it becomes subcritical. Although there is an appreciable energy release in this state, as seen above, the liberation of energy may be regarded as over when the dimensions are just critical. It will be assumed, in the subsequent treatment, that during the very short period while the energy is being released, none escapes from the system. It may be remarked that most of the

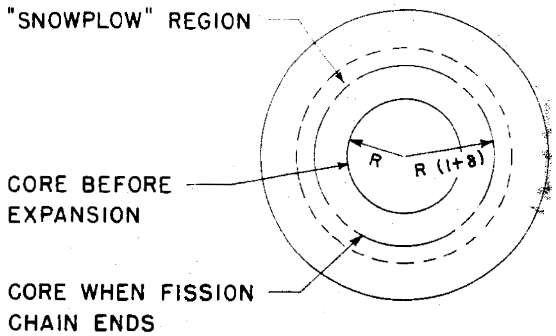

Fig. 2.1

approximations and assumptions involved are applicable when the efficiency is small, and it is for this condition that the Bethe-Feynman treatment is justifiable.

Let R be the radius of the core at the point of maximum supercriticality; then, in accordance with the postulate made above, this will remain unchanged until about the 50th generation after initiation of the fission chain. Subsequently, the energy content of the system becomes so large that mechanical effects begin and the core starts to expand. Suppose that when the core has expanded by a fraction δ, so that the radius is R(1 + δ), the system is just critical (Fig. 2.1). Beyond this point the core material will be subcritical; the fission chain will end and there will be, according to an earlier assumption, essentially no further release of energy.

Consider a thin shell of material in the core, of volume dV and thickness dr; the cross-sectional area of the shell is then dV/dr. If dP is the pressure difference on the two sides of this shell, caused by the fission energy liberated, the net outward force, F, to which the shell is subjected, i.e., pressure x area, is then

$$F = dP \frac{dV}{dr} = \frac{dP}{dr} dV , \qquad (2.2)$$

where dP/dr is the pressure gradient in the given shell. As a reasonable approximation, it may be supposed that the pressure gradient is constant throughout the core, so that it is possible to write

$$\frac{dP}{dr} \approx \frac{P}{R} , \qquad (2.3)$$

where P is the total difference in pressure from the center of the core to the outer surface. Hence, from equations (2.2) and (2.3),

$$F \approx \frac{P}{R} dV . \qquad (2.4)$$

The time required for the core to expand from radius R to R(1 - [illegible] distance of Rδ, is about five generations. However, as a rough approximation this [illegible] taken as 1/α, where α is the multiplication rate when fission is initiated, as described [illegible] n 1.4.

Hence, the mean outward acceleration of the core material, and of the shell dV, may be expressed as $R\delta\alpha^2$. The mass of the shell is $\rho_c dV$, where ρ_c is the core density, and, hence, by Newton's second law of motion, i.e., force = mass x acceleration, the force acting on the shell is given by

$$F \approx R\delta\alpha^2 \times \rho_c dV \ .$$

Upon comparing this result with equation (2.4), it is seen that

$$P \approx \rho_c R^2 \alpha^2 \delta \ . \tag{2.5}$$

At the existing temperatures the core material will be in the gaseous state, and if, as postulated, the loss of energy from the system during the initial expansion is negligible, it may be considered as a gas undergoing an adiabatic process. The total energy of such a gas, which may be regarded as equal to the energy of the core, is then

$$E = \frac{PV}{\gamma - 1} \ , \tag{2.6}$$

where γ is the ratio of the specific heats of the gas. Using equation (2.5) for P and writing M/ρ_c for the volume of the core, M being the mass, equation (2.6) becomes

$$E \approx \frac{MR^2\alpha^2\delta}{\gamma - 1} \ . \tag{2.7}$$

If ϵ is the energy released in the complete fission of unit mass of core material, i.e., about 0.017 kt per gram for uranium-235 and 0.019 kt per gram for plutonium-239, then the total energy available in the core is $M\epsilon$, and the efficiency, by equation (2.1), should be $E/M\epsilon$, where E is given by equation (2.7). However, this is not strictly correct, for in the derivation of this equation no allowance has been made for the depletion of the core material as fission proceeds. For low efficiencies this is, of course, not important, but a distinction will, nevertheless, be made by writing ϕ' for the value obtained using equation (2.7), so that

$$\phi' = \frac{E}{M\epsilon} \approx \frac{R^2\alpha^2\delta}{(\gamma - 1)\epsilon} \ , \tag{2.8}$$

where ϕ' may be related to the true efficiency, ϕ, by a relationship such as

$$\phi = \frac{\phi'}{1 + 1.2\,\phi'} \ , \tag{2.9}$$

sometimes referred to as the depletion correction.

If the tamper density, ρ_t, is not very different from that of the core, then, within a

moderate range of efficiencies, approximate allowance for the effect of the tamper may be made by a factor proportional to $(\rho_t/\rho_c)^n$, where n is less than unity. The limited applicability of the correction may be seen from the fact that it fails completely when there is no tamper, i.e., when ρ_t is zero. However, upon introducing this correction factor, with n = 0.5, into equation (2.8), the result is

$$\phi' \propto \frac{1}{(\gamma - 1)\epsilon} \qquad R^2\alpha^2\delta \sqrt{\frac{\rho_t}{\rho_c}} \; . \tag{2.10}$$

The first factor on the right side is a constant, k, so that equation (2.10) reduces to

$$\phi' \approx kR^2\alpha^2\delta \sqrt{\frac{\rho_t}{\rho_c}} \; , \tag{2.11}$$

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which is one form of the Bethe-Feynman formula. [redacted] Since the total mass of fissile material is known, the actual energy release can also be evaluated.

By comparison with experimental determinations, to be described in Chapter 6, it has been found that while the Bethe-Feynman formula is a useful qualitative guide, it is not always quantitatively correct. For example, the so-called constant, k, varies with the yield and with the composition of the core material, e.g., either plutonium alone, oralloy alone, or combinations of both in various proportions. Hence, normalization procedures must be adopted when using equation (2.11). As an increasing amount of information has become available, it has been found possible to adjust the value of k, and also to make other semi-empirical corrections. Carefully applied, the Bethe-Feynman approximation has been used successfully to design bombs having a wide range of energies. For complex assemblies or where fine distinctions are sought, however, more exact methods of calculating efficiencies are used, e.g., the detailed procedure described earlier or the crits method given below.

Effect of Size and Compression on Efficiency

From an examination of equation (2.11) a number of general conclusions can be drawn concerning the factors affecting the efficiency of a nuclear explosion. In the first place, since the efficiency increases as R^2, it would be advantageous for the core to be large at the time of initiation of the fission chain. This can be achieved in practice by bringing together subcritical masses which are designed to contain a large total amount of fissile material. Thus, for a given compression (or for no compression), the efficiency would be expected to be

greater the larger the mass of the core material. This expectation has been confirmed in numerous tests.

Although compression will result in a decrease in R, this will be more than compensated for by the considerable increase in α^2, for the reasons given in Section 1.4. In addition, the effect of compression on δ must be taken into account; the more highly compressed the core material at the time of initiation, the further will be the distance the surface will travel before the supercritical system becomes just critical. Thus, increased compression should result in a marked increase of efficiency; that this is the case is shown very simply by comparing the yield from a gun-type weapon, in which there is no compression, with that of an implosion weapon.

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The effect of increasing the compression in an implosion weapon is indicated by the data in Table 2.1 which are based partly on experiment and partly on calculation.

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Table 2.1 Effect of Compression on Efficiency

Average Compression		
Core	Tamper	Efficiency (per cent)

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Calculation of Efficiency by the Crits Method

Consider a system containing a mass M of fissile material under a compression C_c; let M_c be the critical mass of the material under these conditions with a specified tamper. Then the number of crits or critical masses, N, present is given by

$$N = \frac{M}{M_c} \tag{2.12}$$

According to equation (1.8), however, M_c is proportional to $1/C_c^2$, and so if M_{co} is the critical mass of the uncompressed material, i.e., when $C_c = 1$, with the same tamper, in the assembled

form, it follows from equation (2.12) that

$$N = \frac{MC_c^{\,2}}{M_{co}} \qquad (2.13)$$

From the general discussion of the Bethe-Feynman formula it was seen that increasing either the mass of fissile material or of the core compression results in an increase of efficiency. It is evident, therefore, from equation (2.13) that the efficiency of a weapon will increase with the number of crits present at the explosion time. This qualitative result is of considerable interest, but a more quantitative development is possible, e.g., by expressing α and δ as empirical functions of the number of crits.

The method used to calculate efficiencies by the crits method is to consider a specific core material, e.g., either oralloy or plutonium, and a given tamper. The efficiencies for various masses of core and a certain compression, which may be unity, are then calculated in any convenient manner, e.g., by the Bethe-Feynman formula. From the results, a curve expressing the variation of efficiency with the number of crits can be drawn. According to the arguments presented above, this curve should apply to all core-tamper systems of the same type, i.e., with the same core material (plutonium or oralloy) and the same ratio of the compressions (or densities) of core and tamper.

Since, for any core of mass M and compression C_c, the number of crits is given by equation (2.13), the efficiency of the corresponding fission weapon can be obtained directly from the curve. A different curve is used, of course, for each core material. Variations in the ratio of core-tamper compressions and in the neutronic thickness of the tamper are taken into account in estimating the critical mass. For composite cores, containing both plutonium and oralloy, semi-empirical adjustments are required to make the crits method applicable to such systems.

The crits method has been found to provide a rapid and reliable procedure for calculating efficiencies. Its main advantage over the Bethe-Feynman formula lies in the fact that the difficult and uncertain neutron theory calculations of α and δ for each case are avoided. The basic curve showing the variation of the efficiency with the number of crits is determined by applying the Bethe-Feynman formula to a simple system for which this formula is known to be reliable.

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2.2 Factors Affecting Efficiency

Effect of Impurities on Efficiency

It was seen in Section 1.2 that the presence of impurities in the fissile material results in an increase in the critical mass. Hence, the number of crits present in a given mass of fissile material will decrease as the proportion of impurity increases. As seen above, a decrease in the number of crits means a decrease of efficiency. Consequently, the efficiency of a weapon will suffer appreciably if nonfissionable impurities are present. For this and other reasons, as will shortly be evident, it is desirable that the fissionable material be as pure as possible. Some indication of the effects on the energy yield of plutonium-240 as an impurity will be given below (Table 2.4).

Effect of Predetonation on Efficiency

The time at which the fission chain is initiated is of paramount importance in determining the yield of a given weapon. [redacted] There is a certain probability that the fission chain will be initiated during this period by a background neutron, but the chance that this will occur at optimum compression is very small. Consequently, it is essential that a neutron source, such as described in Section 1.5, be included to initiate the chain reaction at the proper time. [redacted]

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The effect of predetonation* can be illustrated by reference to Fig. 2.2, in which the ordinates are either the number, N, of critical masses, i.e, crits, or α, the multiplication

*The term "predetonation" as used at LASL refers to initiation before maximum supercriticality. Preinitiation, used by some workers, would be a more appropriate term, but there appears to be little prospect of its general adoption.

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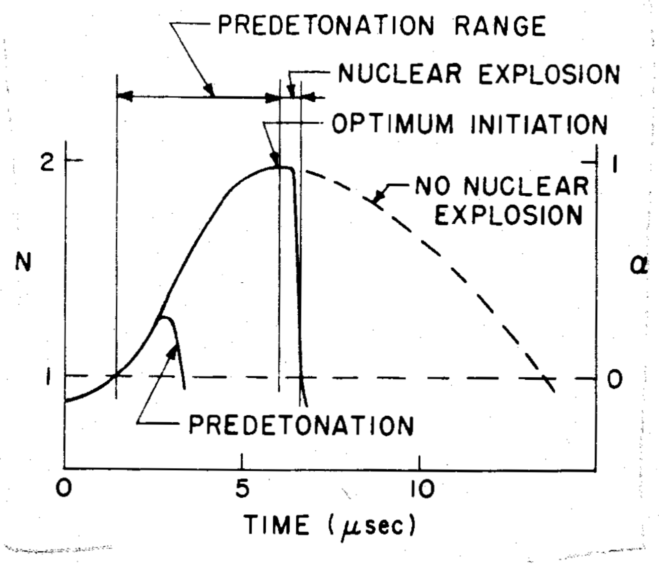

Fig. 2.2

rate, and the abscissae are elapsed time from the beginning of the assembly of a gun-type weapon or compression of an implosion weapon. The numerical values given for N and α are not exact and are intended merely as an indication of the changes which occur. The times, on the other hand, are fairly representative of an implosion weapon. The horizontal dotted line represents the situation for a system that is just critical, i.e., $N = 1$, $\alpha = 0$. Actually, the curves for N and for α as functions of time are somewhat different, and the maxima do not necessarily coincide. However, for the present qualitative discussion, a single curve is adequate.

At zero time the fissile material is subcritical, i.e., $N < 1$, and α is negative, but as compression (or assembly) occurs the value of N increases and α becomes positive, i.e., the system becomes supercritical. If, for some reason, there were no nuclear explosion, the fissile material would suffer decompression, due to its elasticity, after reaching the compression maximum, as indicated by the broken line in Fig. 2.2. In the case of a gun weapon, the parts may fly apart due to the impact.

The optimum yield will obviously be obtained if initiation occurs at the maximum of the curve, i.e., when N has its maximum value. It is at this instant, a few microseconds after compression starts, that the chain should be initiated by the special neutron source. In this event, the whole nuclear explosion will be over in 0.25 to 0.75 μsec, as stated in Section 1.4.

If a neutron entered the core in the period between that at which $N = 1$, $\alpha = 0$ and the maximum of the curve, i.e., while the system is supercritical but before maximum supercriticality is attained, an explosion would occur, but since N would not be as large as is possible, the efficiency will be low. Thus, in order to attain the highest efficiency, predetonation must be avoided. The same will also be true, of course, for postdetonation, i.e., initiation after the maximum of compression has been passed.

The variation of yield with time of initiation may be calculated by any of the methods given above for the determination of efficiency. All that is necessary is to introduce the values of N, α, ρ, etc., which are appropriate to the explosion time in each case. The values

of ϕ will, of course, pass through a maximum, corresponding to the instant of maximum supercriticality.

Oralloy: Neutron Background and Predetonation Probability

In view of the loss of efficiency that would result from predetonation, it is necessary to consider the question of background neutrons, due to spontaneous fission and to the action of alpha particles on light nuclei. Nuclear reactions of the latter type are referred to as (α, n) reactions.

Because of the relatively low rates of spontaneous fission of both uranium-235 and -238, the number of neutrons due to this cause in oralloy is very small. Further, as a result of the very long half lives of both these isotopes, the rate of alpha particle emission is very low. The third naturally occurring isotope, uranium-234, has a half life of 2.35×10^4 years, and so emits alpha particles at an appreciable rate. This isotope is present to the extent of about 1.1 per cent in oralloy. However, the rate of neutron liberation in oralloy as a result of (α, n) reactions with light elements is not very large.

The total background neutron production in oralloy does not exceed about 2 neutrons/sec per kg. [redacted] If P_1 is the probability that a background neutron will be available in the fissile material during the period that the core is supercritical, and P_2 is the probability that this neutron will be able to start a fission chain, then the probability, P, of predetonation is given by

$$P = 1 - e^{P_1 P_2} \approx P_1 P_2 \; , \qquad (2.14)$$

the approximate form being applicable when $P_1 P_2$ is small.

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It should be pointed out that P_2 is a function of time and that both P_1 and P_2 depend, to some extent, on the position of the neutron and other variables. For the present purpose, which is to draw general conclusions only, specific values will be assigned to both P_1 and P_2. A neutron may either escape from the system altogether, or be captured in a nonfission reaction, or produce fission. Although the probabilities of these three processes are by no means equal, it will be postulated here that P_2 has an average value of 0.3 over the predetonation period, in all cases.

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When the shock wave produced by the detonation of the HE inner charge enters the tamper, the latter moves forward, with the attached pusher, through the air space with increasing velocity. As a result, when the tamper reaches the core, it strikes the latter a tremendous, hammer-like blow. More energy is thereby transferred to the core, which is consequently more highly compressed than would be the case in the absence of a free run.

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Fig. 3.4

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Composite Cores

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Fig. 5.9

b(3)

Although the efficacy of the Tom initiator has been proven in several test explosions of complete bombs, a detailed study of some of its characteristics has been made.

Fig. 5.10

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*The maximum rate of neutron production is 2.8 neutrons/μsec per curie of polonium, for the (α, n) reaction with beryllium.

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b(3)

The ENS Initiator

The new external initiator, called the ENS (Experimental Neutron Source), makes use of the fact that 14-Mev neutrons are released in the T-D reaction, between tritium and deuterium nuclei. However, the energy required to make the reaction take place is here supplied by accelerating tritium ions (tritons) in an electrical field; these high-energy ions then impinge upon, and react with, deuterium nuclei.

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Fig. 5.12

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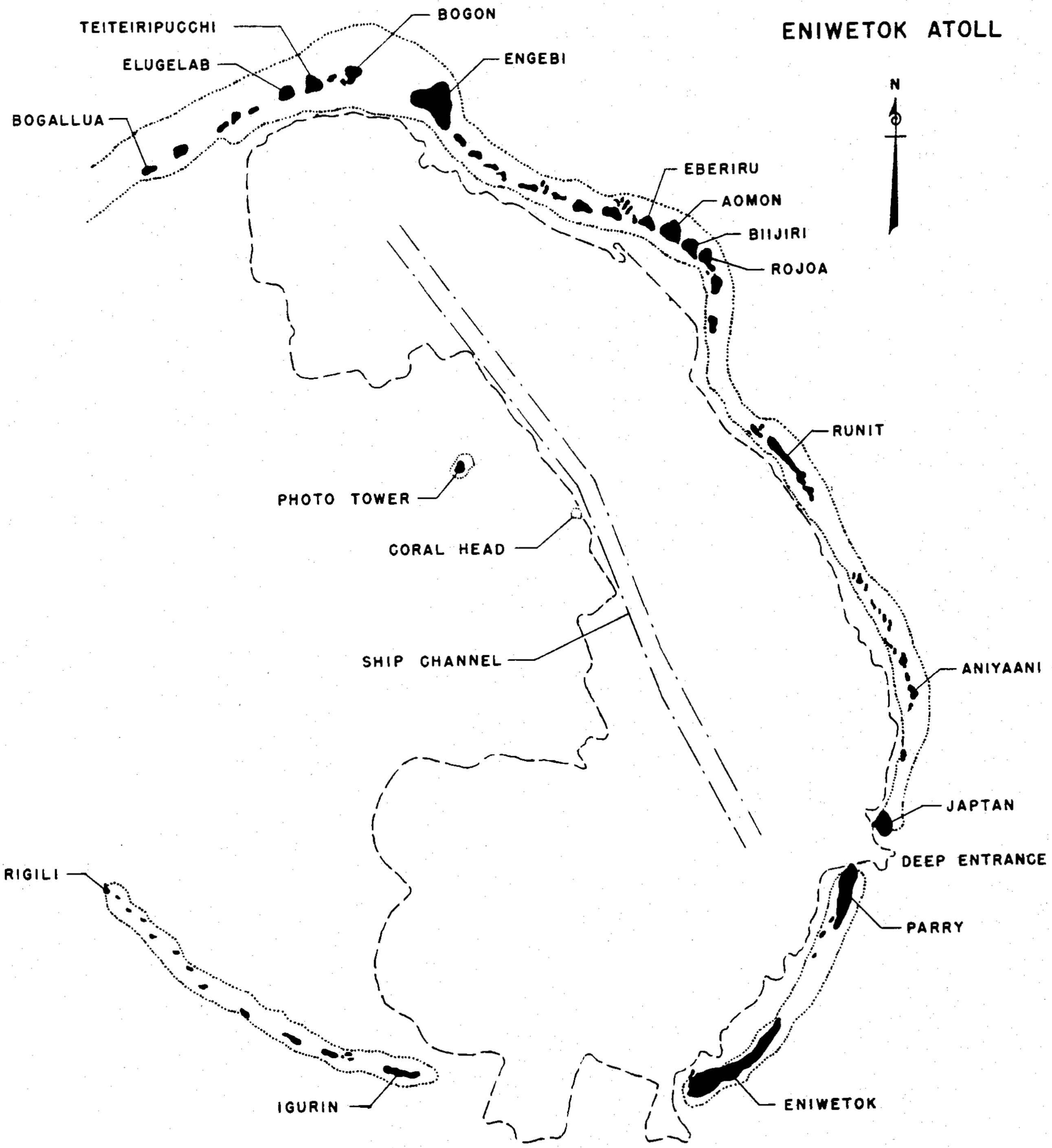

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Fig. 6.2

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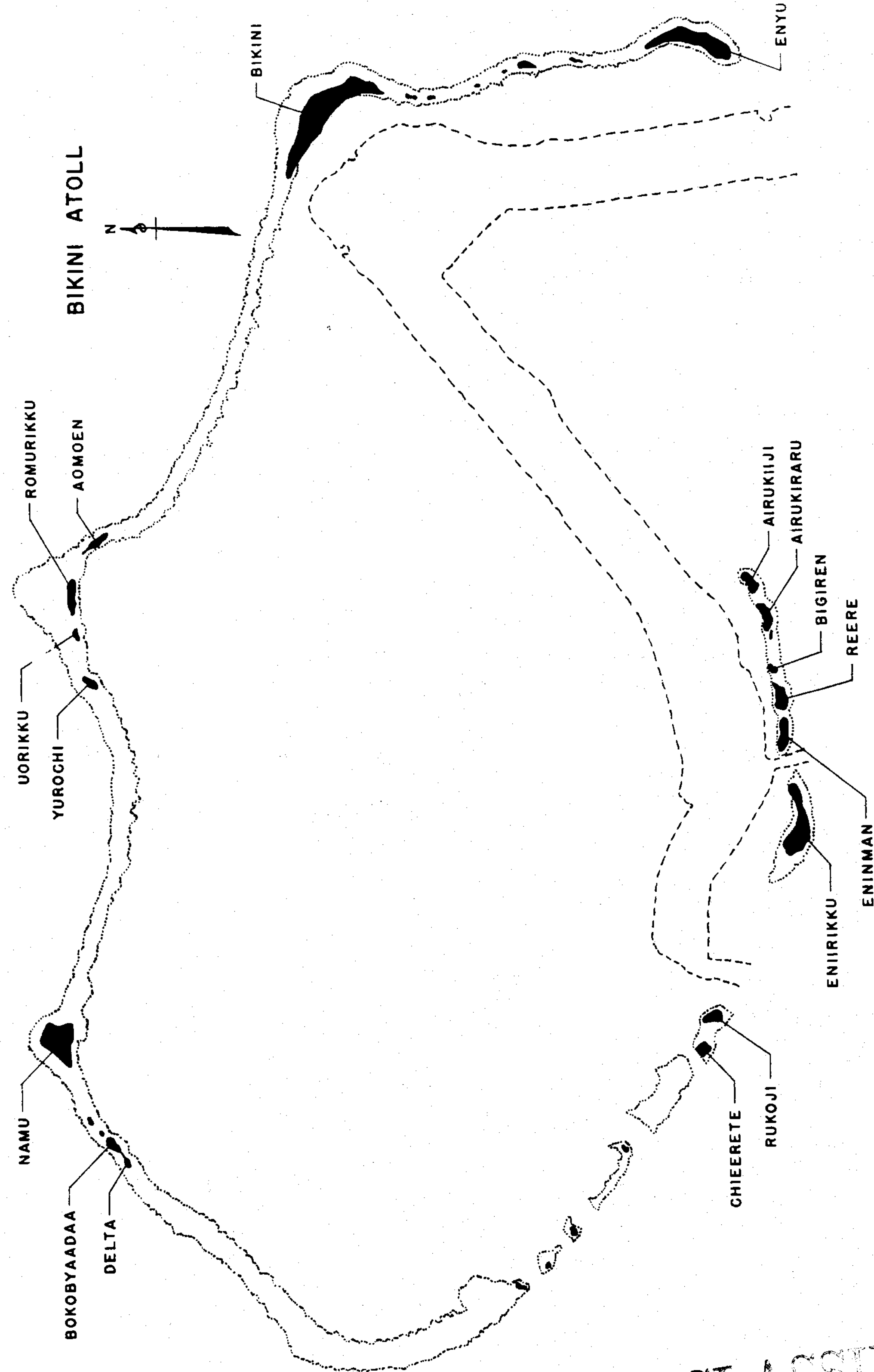

Fig. 6.3

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The fission products which have been used most extensively in efficiency measurements are molybdenum-99 (half life 67 hours) and zirconium-97 (half life 17 hours). These isotopes have convenient half lifes, and their fission yields, which are among the largest, are not greatly dependent upon the energy of the neutrons causing fission. The λy values for molybdenum-99 are almost identical for fission of uranium-235 and plutonium-239, so that no correction is necessary if the bomb core contains both of these fissile species. For this and other reasons, molybdenum is the preferred isotope. For zirconium, the λy's are slightly different and the value used to determine f depends upon the composition of the core.

The fraction θ of the bomb in the post-shot sample can be determined by analyzing for one of the major constituents, e.g., uranium-235, plutonium-239, or total uranium, and correcting for the amounts lost in nonfission reactions, such as (n,γ), $(n, 2n)$, etc. Since the total amount of each of these species present in the original bomb is known, the fraction of the bomb in the sample can be calculated.

Another method for determining the fraction of the bomb in the post-shot sample makes use of a different principle. A radioactive tracer, in known amount, is included in the bomb before detonation. If the quantity present in the post-shot sample is then measured, the fraction of the bomb in the sample can be calculated. The supposition is here, of course, that the tracer is uniformly distributed throughout the whole of the bomb residues, and this may not be the case. Measurements of this kind have been made with polonium-210 as tracer, but with indifferent success. Nevertheless, it is proposed to make further determinations with this isotope and also with curium-242 as tracer.

Determination of Fraction of Fissions in U-235, Pu-239, and U-238

It is of interest to know what proportion of fissions has occurred in uranium-235, plutonium-239, and uranium-238, respectively. Radiochemical methods have been developed for this purpose, although they are not too accurate. The fraction of the total fissions involving uranium-235 is represented by a, the fraction in plutonium-239 by b, and that in uranium-238 by c, so that

$$a + b + c = 1. \tag{6.5}$$

Hence, if any two of a, b, c are determined, the third is known.

The value of c can be obtained by utilizing the experimental fact that the ratio of the cross section for the $U^{238}(n, 2n)U^{237}$ reaction to that for the fission of uranium-238 is roughly constant, independent of neutron attenuation in the uranium. Hence, if the amount of uranium-237 in the bomb residue sample is measured, by means of its radioactivity, the number of uranium-238 nuclei which have undergone fission, and hence, c, can be calculated.

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The determination of a and b is possible, in principle, if there are available two fission products which have very different yields (or activities) for the fission of uranium-235, plutonium-239, and uranium-238. Let

R_{25} = ratio of activities for U-235 fission

R_{49} = ratio of activities for Pu-239 fission

R_{28} = ratio of activities for U-238 fission,

so that the observed activity ratio, R, is given by

$$R = aR_{25} + bR_{49} + cR_{28}. \qquad (6.6)$$

Since a + b + c = 1, then, if the three activity ratios, R_{25}, R_{49}, and R_{28}, have been determined, any two of the fractions a, b, c, can be calculated provided the third is known. For weapons containing only uranium-235 or plutonium-239 as the fissile material, the problem is, of course, simplified.

Of the pairs of isotopes that may be used in the foregoing connection, one is always chosen to be molybdenum-99; the other may be silver-111, palladium-112, cadmium-115, or cerium-136. Although the method is sound, in principle, it has not yet given satisfactory results. This is believed to be due to a partial separation (or fractionation) of the elements present in the fission products. Consequently, the post-shot samples do not always have the same composition as the bomb residue as a whole. Such is not the case for molybdenum-99, and that is one reason why this isotope is much used in yield determinations.

Provided c is known, a and b can be calculated if the measured ratio of uranium-235 to plutonium-239 in the post-shot sample is compared with the known ratio in the original bomb. This method involves corrections for the amounts of these two isotopes lost in nonfission reactions, as well as for the formation of plutonium-239 as a result of neutron capture by uranium-238, followed by two stages of beta decay.

In a test shot the fraction a can be measured by incorporating into the oralloy an indicator, such as titanium, thorium, thallium, or tungsten. The titanium and thorium react with fast neutrons, i.e., $Ti^{47}(n,p)\ Sc^{47}$ and $Th^{232}(n,2n)\ Th^{231}$, respectively, whereas the thallium and tungsten capture slow neutrons, i.e., $Tl^{203}\ (n,\gamma)\ Tl^{204}$ and $W^{186}\ (n,\gamma)\ W^{187}$ followed by $W^{187}\ (n,\gamma)\ W^{188}$, to form characteristic, identifiable products. By assuming that the uranium-235 and the indicated isotope have been subjected to the same neutron flux, it is possible, from a determination of the product formed and the known cross section of the reaction, to calculate the number of uranium-235 nuclei which have undergone fission.

Somewhat analogous procedures can be used to determine b, except that, as in the method described above for c, the indicator or detector species is already present. In addition to undergoing fission, plutonium-239 is involved in the reaction Pu^{239} (n,γ) Pu^{240} Consequently, if the amount of plutonium-240 present in a post-shot sample is determined, and allowance made for the proportion in the original plutonium and the amount lost in various neutron reactions, the number of plutonium-239 fissions can be calculated. It is of interest to note that the plutonium-240 is determined with a mass spectrograph rather than by its radioactivity. The alpha particles from the 240-isotope are not easily distinguished from those emitted by plutonium-239 because of their similar energies.

Another reaction for determining b is Pu^{239} (n, 2n) Pu^{238} with fast neutrons. In this case, the amount of plutonium-238 in the bomb residue sample can be estimated from its alpha radioactivity since the particles can be resolved from those emitted by the other plutonium isotopes.

The plutonium used in weapons invariably contains some plutonium-241 as an impurity; this is a beta-particle emitter with a half life of 14 years, the decay product being americium-241, half life 470 years. It is seen, therefore, that the plutonium components of bomb cores which have been stored for some time will contain appreciable amounts of americium-241. In the exploding bomb, the latter will undergo the reaction Am^{241} (n,γ) Am^{242}, followed by beta decay of the americium-242 to form curium-242. The curium-americium ratio in the post-shot sample will thus be roughly proportional to the amount of fission which has occurred in the plutonium-239.

Sample Collection

The collection of representative samples for radiochemical analysis after a nuclear explosion has proved to be quite a difficult matter. For reasons not clearly understood, fractionation occurs in the highly complex system, so that a particular portion of the bomb residue may not have the same composition as the average of the whole. In addition to the requirement that the post-shot sample shall be representative, it must be of sufficient size to make accurate analysis possible; it must not be contaminated during collection, and it must be capable of relatively rapid recovery and delivery to the laboratory.

Various methods of sample collection have been tried out at one time or another; the most satisfactory results have been obtained either by the use of drone aircraft guided through the atomic cloud after an explosion or by means of manned aircraft flying into the cloud. The samples collected are of two types: "snap" samples in which a container is filled with essentially gaseous material, and particulate samples obtained by drawing the air and other gases through a filter. The mission of the manned aircraft is planned so as to give satisfactory samples with minimum radiation exposure of the crew.

fireball surface, is of special interest. This has been referred to in Section 6.3 as the prompt or effective thermal radiation. The latter description is applied because it is this radiation which is responsible for skin burns, and possibly of fires out to considerable distances from a nuclear explosion. Prompt thermal radiation studies are thus of interest, not only because they provide information concerning the phenomena of a nuclear explosion, but also because of the importance of these thermal radiations from the weapons standpoint. Measurements are usually made of the total energy released as prompt thermal radiation and of the energy variation with time.

The total prompt thermal radiation is measured in two ways. One method makes use of a conventional ballistic thermocouple, the output of which is measured with a thermopile recorder connected to a photoelectronic galvanometer. In the other method a blackened container is filled with air which expands, due to the temperature increase, when radiation is absorbed. The amount of the latter is calculated from the movement of a diaphragm indicator. By using data for the transmission of radiation by the atmosphere just prior to the explosion, such as those described earlier, the total energy liberated by the bomb as prompt thermal radiation can be estimated.*

It was thought at one time that a definite fraction of the energy of the explosion appears as prompt thermal radiation. More recent measurements have shown, however, that this fraction varies with the bomb yield. The results can be expressed, to a fair degree of accuracy, by the relationship

$$Y_{th} = 0.42Y^{0.9} \pm 0.04 \qquad (6.14)$$

where the prompt thermal radiation yield, Y_{th}, and the total bomb yield, Y, are expressed in kilotons. It follows, therefore, that for a 20 kt bomb about 28 per cent of the energy is released as prompt thermal radiation, but in a 100 kt bomb the proportion is only 23 per cent.

The amount of radiation energy, Q, delivered per unit area at a distance D from the explosion is represented by

$$Q = \frac{Y_{th}}{4\pi D^2} e^{-kD} \qquad (6.15)$$

where k is the attenuation coefficient of the air for the thermal radiation emitted in the explosion. The value of k, which determines the transmission of radiation, depends on the state

*The transmission coefficient depends to a marked extent on the wavelength of the radiation and this must be taken into account in the calculation.

Because of the very short exposures, the attenuation of light between the ball of fire and the camera, several miles away, is very important. It is necessary, therefore, to monitor the light path prior to the test shot, by the method already described, if high-speed photography is to be used for ball-of-fire measurements.

Rotating Mirror (Streak) Cameras

The rotating mirror, streak cameras used in weapons tests are essentially the same as those described in Chapter 4 for testing detonators and HE lenses. A rotating mirror reflects light continuously from a number of sources on to a film strip; the distance between the points at which the traces from the different sources commence is a measure of the time interval between the initiation of the respective sources. The writing speed is such that 2 mm is equivalent to 1 μsec. The essential purpose of the streak cameras in weapons tests is thus to determine elapsed time between two or more events.

One such use is to measure the time interval between the fission and fusion reactions in separate parts of a two-stage thermonuclear device. Each type of process will induce Teller light (see Section 6.4) in the surrounding air, so that two streaks will appear on the camera film. The distance between the beginning of the two streaks gives the time between the two reactions.

Another application of the rotating mirror, streak camera is to determine shock velocity and pressure within a device by studying so-called "hot spots." These are points (or small areas) down the length of a case at which the arrival of the shock front from a fission bomb is indicated by strong light emission. By means of a pipe and mirror arrangement, the camera observes only certain selected points, the light from all other parts of the bomb being blocked out. From the positions of the streaks indicating the arrival of the shock front at successive points a known distance apart, the velocity and shock wave and, hence, the shock pressure can be calculated.

The propagation of the shock wave through a particular metal, which is part of the bomb case, can also be studied by the hot-spot procedure. This is done by making the shock wave traverse different thicknesses of the metal, by drilling the bomb case at some points and adding pads of the same material at others. The various spots will thus become luminous at different times and the intervals between them can be estimated from the camera streaks.

6.10 Thermonuclear Burning Studies

Tenex Measurements

The primary purpose of the Tenex (temperature neutron experiment) measurements is to make use of the 14-Mev neutrons produced in the D-T reaction to estimate the thermonuclear

burning temperature. Strictly speaking, these neutrons have an energy of 14 Mev only if the reacting deuterium and tritium nuclei are at rest. But if these nuclei are in motion, the neutron energy will be 14 Mev plus four fifths of the kinetic energy of the reacting particles in the center-of-mass (C-of-M) system. Actually the center of mass is in motion relative to the observer, so that there is a Doppler energy shift superimposed on the energy in the C-of-M system. Consequently, neutrons released in the D-T reaction will have energies covering a band in the vicinity of 14 Mev. The higher the velocity of the particles, i.e., the higher the nuclear temperature, the broader the band. The velocity distribution is roughly Gaussian, with the half width depending on the temperature.

A scintillation detector is placed at a considerable distance from the explosion, so that neutrons of different energies belonging to the 14-Mev group arrive at different times. These are recorded on a synchroscope, and the velocity distribution can then be determined from the observed "times of flight." From this distribution, the temperature of the thermonuclear reaction system can be estimated. *

When studying thermonuclear devices of high energy yield, the recording instruments must be located a considerable distance away. If the detectors can be placed near the explosion point, long cables are necessary to transmit signals to the recorders. Such lines must be protected from extraneous gamma radiations by extensive earth fills which are costly. On the other hand, if the detectors are close to the recording instruments, the radiations from the bomb, e.g., neutrons and gamma rays, suffer considerable attenuation due to absorption, so that weak signals are received.

In the Ivy tests the problem was solved by transmitting the radiations through a helium channel since this gas is a poor absorber for both neutrons and gamma rays. The channel consisted of a plywood box, 8 ft by 8 ft in cross section and nearly 9,000 ft long, filled with a number of thin-walled polyethylene balloons containing helium gas at slightly above atmospheric pressure. Lead baffles inserted in the box served to provide a number of well-collimated paths, which were used for Tenex and other measurements related to thermonuclear burning.

In order to reduce attenuation still further, an evacuated metal pipe, 6 inches internal diameter and about 7,500 feet in length, is to be used as the radiation path in the Castle tests. A pressure of 0.1 atm is believed to be adequate for the purpose, although it is expected that a much higher vacuum will be maintained.

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*The energy distribution can also be determined, and the temperature estimated, by the Phonex measurements described in Section 6.6.

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By Donald P. Dickason / Jim Dominic

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WEAPONS ACTIVITIES

of

LOS ALAMOS SCIENTIFIC LABORATORY

PART II (U)

by

Samuel Glasstone

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$$D^2 + D^2 \begin{cases} \rightarrow He^3 + n^1 + 3.27 \text{ Mev} \\ \rightarrow T^3 + H^1 + 4.04 \text{ Mev} \end{cases}$$

$$D^2 + T^3 \longrightarrow He^4 + n^1 + 17.6 \text{ Mev}.$$

It is seen that there are two alternative D-D reactions; they take place roughly at the same rates, so that each may be regarded as occurring in half the D-D interactions.

D-D and D-T Cross Sections

The rate of a nuclear process is usually expressed in terms of the effective area per nucleus, i.e., the cross section. These cross sections can be determined experimentally by accelerating deuterons or tritons to known energies and determining the extent of interaction with other (stationary) nuclei. The results obtained for the second of the D-D reactions given above, represented by DD_p, and for the D-T reaction are shown in Fig. 8.2. The values for the other D-D reaction are very similar. The cross sections, $\sigma(E)$, are expressed in barns, i.e., in units of 10^{-24} cm^2, as a function of the deuteron energy in kev.

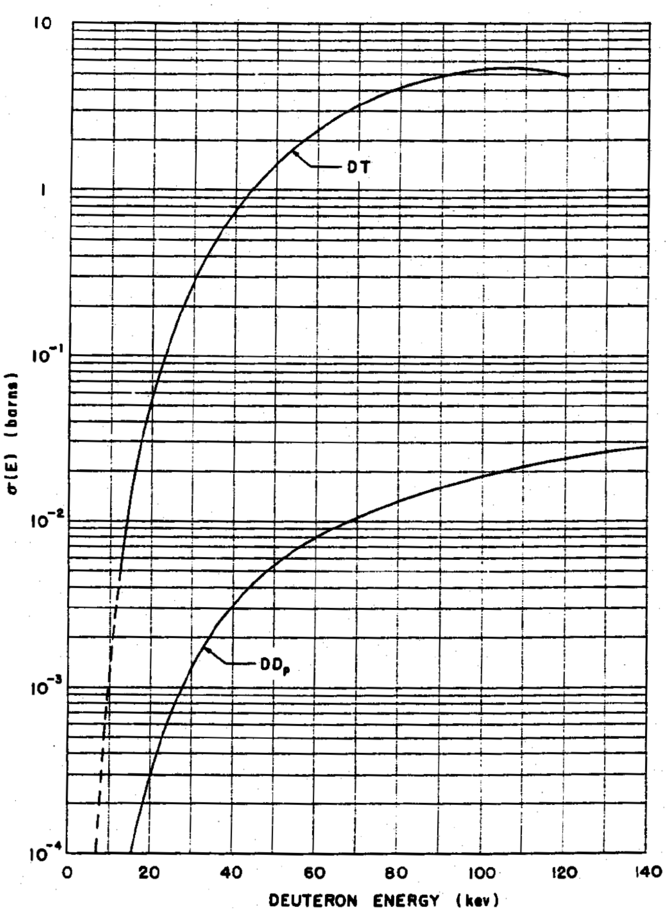

Fig. 8.2

The cross section, or reaction rate, is seen to increase with the energy, due to the increased probability of penetration of the potential barrier. It may be mentioned that the cross-section curve for the D-T reaction is not only somewhat higher than expected, but it also exhibits a maximum at energies around 100 kev (see Fig. 8.2). This is attributed to the phenomenon of resonance.

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Calculation of Reaction Rates

Consider a quantity of deuterium, and let the cross section, σ, represent the effective area of a nucleus of a given energy for the D-D reaction. If v is the velocity of the deuterium nucleus, then it will sweep out an effective volume σv in unit time, e.g., per sec. If there are N deuterons per cm^3, then the total effective volume swept out is σvN per cm^3 per sec. Since there are N deuterons present per cm^3, the number of effective D-D collisions, i.e., the rate of the D-D reaction, is equal to $\sigma vN^2/2$ per cm^3 per sec. The factor of one half is introduced here, for otherwise each D-D collision is counted twice. In the case of the D-T reaction, the corresponding rate would be σvN_dN_t per cm^3 per sec, where N_d and N_t are the numbers of deuterons and tritons, respectively, per unit volume.

It is seen from the foregoing argument that, apart from the density of the material, i.e., the number of nuclei per cm^3, the rate of a nuclear reaction is determined by the product σv. In a system at a given temperature, T, not all the nuclei will have the same energy and, hence, velocity.* The energies will, in fact, be distributed over a large range from very small to very large, as indicated qualitatively, in Fig. 8.3; $n(E)/n$ is the fraction of nuclei having energy E, per unit energy interval. If the energy distribution follows the Maxwell law, then the energy corresponding to the most probable velocity, per unit velocity interval, is equal to kT, where k is Boltzmann's constant; this is generally referred to as the energy corresponding to the temperature T.

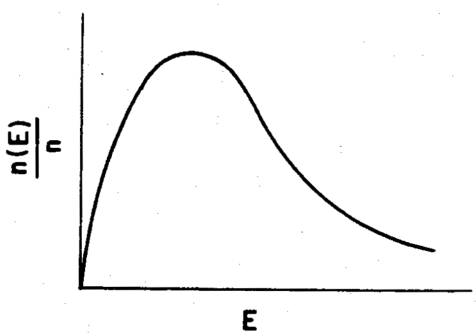

Fig. 8.3

As implied earlier, it has become the practice in the thermonuclear field to state the temperature as the energy kT, usually expressed in kev. Since k is 8.62×10^{-8} kev per degree, it follows that

$$\text{Temperature in kev} = 8.62 \times 10^{-8}\ T ,$$

where T is the absolute (Kelvin) temperature. Thus, a so-called temperature of 1 kev would correspond to a Kelvin temperature of 1.16×10^7 degrees.

*Since the energy E is kinetic, it is equal to $1/2\ mv^2$, where m is the mass of the nucleus; hence, v is determined by E, for a given species.

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In order to determine the rate of a nuclear reaction at a given temperature, it is necessary to obtain a proper weighted average of σv, i.e., $\overline{\sigma v}$, over the whole energy range, since both σ and v vary with the nuclear energy. This can best be done by taking the experimental values of σ as a function of E (or of v), from Fig. 8.2, multiplying by the corresponding velocity, v, and then weighting each product according to the Maxwellian probability of that velocity. This operation may be expressed analytically by

$$\overline{\sigma v} = \frac{\int [\sigma(v)v] \; v^2 e^{-\frac{mv^2}{2kT}} \, dv}{\int v^2 e^{-\frac{mv^2}{2kT}} \, dv}, \qquad (8.5)$$

where the integrand in the denominator is the Maxwell factor. The values of $\overline{\sigma v}$ for one of the D-D reactions and for the D-T reaction, obtained somewhat in this manner, are plotted in Fig. 8.4 as a function of the temperature in kev. It is seen that, under equivalent density conditions, the D-T reaction is of the order of 50 to 100 times as fast as each of the D-D reactions at the same temperatures, at least in the range from 1 to 100 kev.

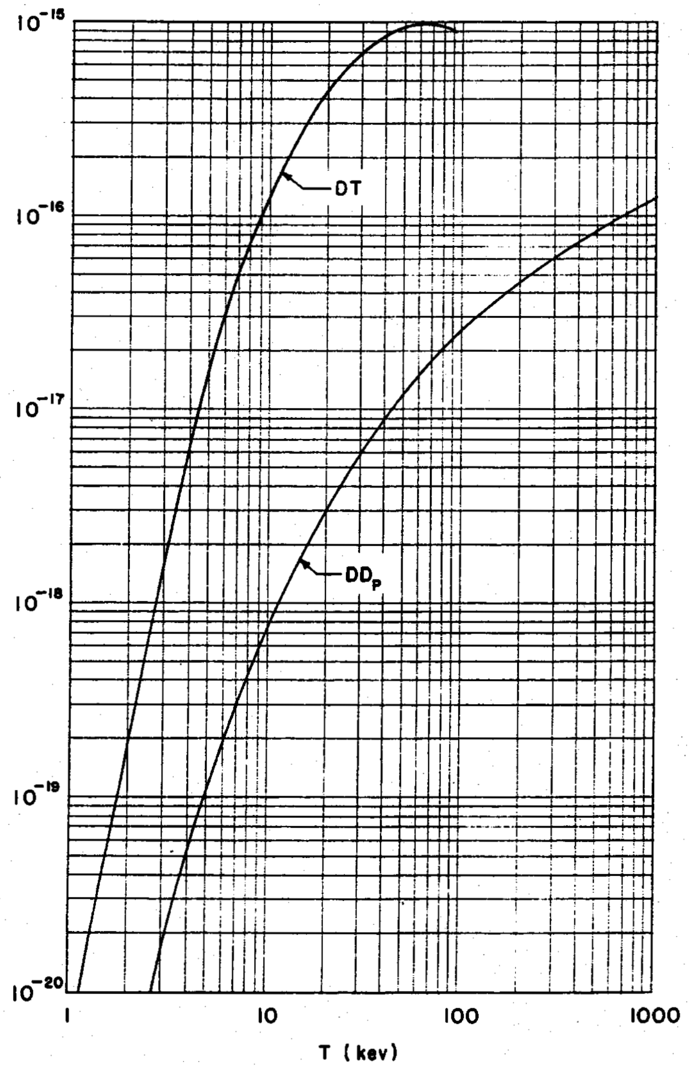

Fig. 8.4

The Reproduction Time

To illustrate the use of the data in Fig. 8.4, the energy reproduction time, i.e., the time required for the energy to double itself, in deuterium will be calculated. In every effective D-D collision, two deuterons are consumed, but in (roughly) half of these reactions a tritium nucleus is produced, which rapidly undergoes the D-T interaction with another deuterium nucleus. Thus, on the average, 2.5 deuterons are used up in every

effective collision.* From the arguments presented above, the number of effective D-D collisions is $\overline{\sigma v}N^2/2$ per cm^3 per sec, and so deuterons are consumed at the rate of $2.5\ \overline{\sigma v}N^2/2$ per cm^3 per sec. Since N is the number of deuterons present per cm^3, the fraction, F_t, of the deuterium reacting in time t sec is given by

$$F_t = \frac{2.5}{N}\ \overline{\sigma v}\ \frac{N^2}{2}\ t = 1.25\ \overline{\sigma v}\,Nt\ , \qquad (8.6)$$

where t is assumed to be so short that N does not decrease appreciably.

If the two D-D reactions take place to, approximately, the same extent and every tritium nucleus formed rapidly undergoes the D-T reaction with another deuteron, the total energy liberated will be 4.04 + 3.27 + 17.6 = 24.9 Mev or, roughly, 25 Mev, for the consumption of five deuterons, i.e., 5 Mev or 5000 kev per deuteron. The energy ΔE produced in time t, per deuteron present in the system, is equal to F_t x 5000 kev, and so

$$\Delta E = 6250\ \overline{\sigma v}Nt \text{ kev per deuteron.}$$

If E_{tot} is the total energy per deuteron present in the system, then the reproduction time, t_{rep}, i.e., the time required for the energy to double itself, due to the D-D and D-T reactions, is given by

$$t_{rep} = \frac{E_{tot}}{6250\ \overline{\sigma v}\,N}\ . \qquad (8.7)$$

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Production of Lithium-6

The enrichment of lithium-6, from its normal isotopic proportion of 7.3 per cent to the 95 per cent or so desirable for thermonuclear devices, is carried out by a chemical, isotopic exchange process. Lithium amalgam, consisting of a solution of metallic lithium in mercury, is allowed to interact with an aqueous solution of lithium hydroxide in water. As a result of the exchange between the lithium isotopes in the mercury and those present as ions in the water, the ratio of lithium-6 to lithium-7, at equilibrium, is larger in the amalgam than in the aqueous solution. The separation coefficient is not much greater than unity, and appreciable enrichment is achieved by a continuous counter-current process. The lithium amalgam, flowing in one direction, becomes steadily richer in the Li^6 isotope, whereas the proportion of lithium-7 increases in the hydroxide solution. Because of the separation difficulties, highly enriched lithium-6 is still rare and costly.

8.6 Thermonuclear Tests

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FOREWORD

While this document has been published as a Headquarters, U. S. Atomic Energy Commission publication, it has as its genesis two 1954 Los Alamos Scientific Laboratory reports identified as LA-1632 and LA-1633, titled "Weapons Activities of LASL." These publications are well known and used extensively by those interested in nuclear weapons as basic handbooks on the principles of nuclear weapons development and technology. Dr. Samuel Glasstone has revised and consolidated the above reports incorporating information furnished by the Los Alamos Scientific Laboratory, Lawrence Radiation Laboratory—Livermore, The Sandia Corporation, and the Defense Atomic Support Agency.

This document has been prepared solely for reference purposes on the principles of atomic weapons development and should not be considered as a technical guide for designing nuclear weapons.

Since this issue contains highly sensitive atomic weapons information of significance to our national defense and security, all viewers are enjoined to insure its proper security protection at all times.

A. W. Betts
Major General, USA
Director of Military Application
U. S. Atomic Energy Commission

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$$R_c \propto \lambda \tag{1.6}$$

1.44 The greater the probability of the interaction of a neutron with a nucleus, the smaller will be the distance the neutron travels before interacting. Hence, the neutron mean free path is related inversely to its interaction probability. This probability is proportional to the number of fissile nuclei per unit volume, and hence to the density; if ρ is the density of the core material, then

$$\lambda \propto \frac{1}{\rho} \tag{1.7}$$

It follows therefore from equations (1.6) and (1.7) that

$$R_c \propto \frac{1}{\rho} \tag{1.8}$$

1.45 The critical mass, M_c, is equal to the product of the critical volume, which is $\frac{4}{3}\pi R_c^3$, and the density of the fissile material; hence,

$$M_c = \frac{4}{3}\pi R_c^3 \rho$$

Upon substituting equation (1.8) for R_c, it is seen that

$$M_c \propto \frac{1}{\rho^2} \tag{1.9}$$

The density of the material is dependent upon the degree of compression; thus, if η is the compression ratio, i.e., the ratio of the volume before to that after compression, then

$$\rho \propto \eta$$

and substitution in equation (1.9) leads to the result

$$M_c \propto \frac{1}{\eta^2} \tag{1.10}$$

The critical mass of a given fissile material, under specified conditions, is thus inversely proportional to the square of the compression ratio. The proportionality constant is readily derived by writing M_{c0} for the critical mass of the uncompressed material, i.e., when $\eta = 1$. It follows then from equation (1.10) that

$$M_c = \frac{M_{c0}}{\eta^2} \tag{1.11}$$

1.46 An alternative way of stating this result is in terms of the number of crits (or critical masses), C, present in the compressed core. If M is the actual mass of fissile material, the number of crits in the compressed state is defined by

$$C = \frac{M}{M_c}$$

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[redacted]

Combination with equation (1.11) then yields

$$C = \frac{M\eta^2}{M_{c0}} = C_0\eta^2 \tag{1.12}$$

where M/M_{c0} has been replaced by C_0, the number of crits before compression. [redacted] The introduction of neutrons into this highly supercritical system resulting from compression will cause a very rapidly divergent fission chain reaction to develop. In these circumstances there is very efficient use of the fissile material for the release of energy. It is the high degree of supercriticality (and increased efficiency) attainable by compression that constitutes the great advantage of implosion-type weapons over those of the gun type.

DOE b(3)

1.47 Strictly speaking, the relationship of the number of crits to the square of the compression holds only for a bare core. For a tamped core, a more correct form of equation (1.12) is

$$C = C_0\eta_c^{1.2}\eta_t^{0.8}$$

where η_c is the compression of the core and η_t is that of the tamper. Since the tamper is generally compressed less than the core, a good approximation for weapons is to write

$$C = C_0\eta_c^{1.7}$$

The effect of compression is still substantial, although not as large as is implied by equation (1.12).

Fusion Reactions in Fission Weapons

1.48 It was stated in §1.2 that the large-scale release of energy in weapons is possible by making use of fusion reactions in which two very light nuclei combine (or fuse) together to form particles of greater mass. However, apart from the application of nuclear fusion reactions as a source of energy, described in Chapter 7, certain fusion processes are important in the design of fission weapons for another reason. The significance of these reactions does not lie in the energy released but in the neutrons which are produced. Three fusion reactions, involving the less common isotopes of hydrogen, namely, deuterium (D^2) and tritium (T^3), are of interest in this connection. Two of these reactions are between pairs of deuterium nuclei (deuterons) only, i.e.,

$${}_1D^2 + {}_1D^2 \rightarrow {}_0n^1 + {}_2He^3$$

and

$${}_1D^2 + {}_1D^2 \rightarrow {}_1H^1 + {}_1T^3$$

which take place at about the same rate, and the third is a much more rapid interaction between a deuteron and a tritium nucleus (triton), i.e.,

$${}_1D^2 + {}_1T^3 \rightarrow {}_0n^1 + {}_2He^4$$

1.49 It is seen that when two deuterons interact, a neutron is formed in one case and a triton in the other; the triton then readily reacts with a deuteron to produce another neutron. Both deuteron-deuteron (D-D) and deuteron-triton (D-T) reactions are employed to provide

neutrons for initiating fission chains. In addition, the high-energy (14 Mev) neutrons liberated in the D-T reaction are used in many fission weapons to achieve what is known as "boosting." Neutrons from the D-T reaction are introduced at a later stage of the fission chain in order to maintain and enhance the progress of the fission reactions. There is a considerable increase in the energy released because of the greatly improved efficiency in utilization of the fissile material. The energy contributed by the D-T fusion reaction is quite small in comparison with that from fission.

PRODUCTION OF WEAPONS MATERIALS

Uranium-235

1.50 The two important fissile materials, namely, uranium-235 and plutonium-239, are both produced from natural uranium but by entirely different procedures. Ordinary uranium contains about 0.7 percent of uranium-235, together with about 99.3 percent of uranium-238 and a trace (0.006 percent) of uranium-234. The proportion of uranium-235 is increased by a process involving diffusion or, more correctly, effusion through porous barriers of the vapor of uranium hexafluoride (UF_6) made from natural uranium. The hexafluoride of the lighter isotope diffuses more rapidly than does that of the heavier species, and by the use of several thousand diffusion stages enrichments of over 90 percent are obtained, i.e., the material produced contains over 90 percent of uranium-235. The most common product for weapons use consists of about 93.5 weight percent uranium-235, the remainder being mainly uranium-238 and a small proportion of uranium-234. This product is commonly known as "oralloy," the two initial letters standing for Oak Ridge, where the material was first made in quantity.*

DOE b(3)

1.51 The highly enriched uranium hexafluoride obtained from the gaseous diffusion plant is converted into the tetrafluoride (UF_4) by reduction with hydrogen (mixed with some fluorine). The tetrafluoride, which is a solid with a high melting point (close to 1000°C), is mixed with calcium and heated in a closed steel vessel lined internally with a refractory material. The calcium reduces the uranium tetrafluoride to uranium metal which is separated from the slag of calcium fluoride. Volatile impurities are removed by heating the liquid metal in a vacuum and the resulting product is of a high degree of purity.

1.52 The residual material from the isotope separation (gaseous diffusion) plant consists of uranium hexafluoride which has been depleted in uranium-235. In other words, it contains more than the normal 99.3 percent of uranium-238. This is converted into uranium metal by a procedure similar to that described above. It is referred to as depleted uranium or, in the weapons program, as D-38. At one time it was called Q-metal, but this name is not now in common use.

Plutonium-239

1.53 The element plutonium does not occur in nature, except in insignificant traces. Consequently, the plutonium-239 used in weapons is obtained artificially by a series of nuclear reactions resulting from exposure of uranium-238 to slow neutrons in a nuclear reactor. A nuclear reactor is a device in which a fission chain reaction is taking place in a controlled manner, as against the deliberately uncontrolled chain reaction in a weapon. If a material of low mass number, called a moderator, is present, in addition to fissile material, the fission neutrons are slowed down. Such a nuclear reactor is thus a good source of slow neutrons.

*The "alloy" part of the name originated from the designation Tube Alloys Limited applied to the British wartime atomic energy project. Natural uranium metal was thus called "tuballoy," a term still in common use, and then oralloy was adopted for the uranium-235 enriched material.

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efficiencies were estimated by the method of Bethe and Feynman. The basic formula is admittedly approximate, since it involves several simplifying assumptions. However, its derivation is useful in the respect that it provides a model of the explosion of a fission weapon and indicates, qualitatively at least, some of the factors which affect the efficiency of the explosion. The treatment given below is applicable to pure fission systems and not after boosting occurs.

2.29 As a result of the energy liberated in fission, very large pressures (~10^8 atm) are developed in the core, and the core-tamper interface consequently receives a large outward acceleration. This causes highly compressed tamper material to pile up just ahead of the expanding interface, in an effect referred to as the "snowplow" phenomenon, because of the similarity to the piling up of snow in front of a snowplow. The inertia of the compressed tamper delays expansion of the core, so that a considerable pressure gradient builds up from the center of the core to its outer surface.

2.30 Furthermore, because of the delayed expansion, it may be supposed that the volume of the compressed (supercritical) core remains essentially constant during the [redacted] so generations following initiation of the fission chain, i.e., up to explosion time. After this interval, almost the whole of the energy is released within an extremely short period, during which time the supercritical core expands rapidly until it becomes subcritical. Although there is an appreciable release of energy even while the system is subcritical, as mentioned in §2.27, it will be postulated that energy production ceases when the dimensions are just critical. It will be assumed, further, that no energy escapes during the short period of expansion from maximum supercriticality to the point where the system becomes subcritical. DOE b(3)

2.31 Let R be the radius of a spherical core at the point of maximum supercriticality; then, in accordance with the postulate made above, this will remain unchanged until explosion time. Subsequently, the energy density of the system becomes so large that mechanical effects begin and the core starts to expand. Suppose that when the core has expanded by a fraction δ, so that the radius is $R(1 + \delta)$, the system is just critical (Fig. 2.1); beyond this point it will be subcritical. The self-sustaining fission chain will then end and, in accordance with the approximation postulated above, there will be no further release of energy.

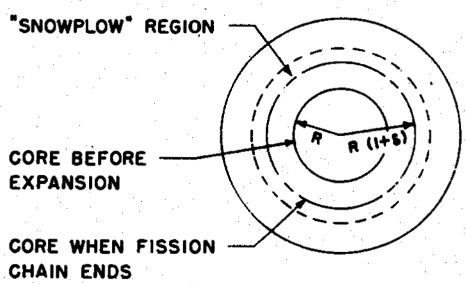

Figure 2.1

2.32 Consider a thin shell of material in the core, of volume dV and thickness dR; the cross sectional area of the shell is then dV/dR. If dP is the pressure difference on the two sides of this shell, caused by the liberated fission energy, the net outward force, dF, to which the shell is subjected, i.e., pressure × area, is then

$$dF = dP\frac{dV}{dR} = \frac{dP}{dR}dV \qquad (2.14)$$

where dP/dR is the pressure gradient in the given shell. As a reasonable approximation, it may be supposed that the pressure gradient is essentially constant across the core radius, so that

which is a simplified version of the Bethe-Feynman formula. The efficiency of a fission weapon is seen to depend on the factors R, α, and δ.

2.36 Since the efficiency of a fission weapon may be expected to increase as R^2, it would be advantageous for the core to be large at the time of the initiation of the fission chain. One way in which this can be achieved in practice, e.g., in a gun-type weapon, is to bring together subcritical masses which are designed to contain a large total mass of fissile material. Thus, for a given compression or, especially, for no compression, the efficiency would be expected to be greater the larger the mass of the assembled core.

2.37 In general, the most important factor in determining the efficiency of a fission weapon is α; as seen in §2.16, this increases in proportion to the compression. The efficiency, according to equation (2.21), will thus be related, approximately at least, to η^2 (or to $\eta^{1.7}$ if the effect of tamper compression is taken into account). In addition, although of lesser significance, the effect of compression on δ must be taken into account; the more highly compressed the core material at the time of initiation (or at explosion time), the farther will be the distance the core surface must travel during the expansion phase before the supercritical system becomes subcritical. Increased compression should thus result in a marked gain in the efficiency of a fission weapon. It is this fact which is largely responsible for the much higher efficiencies of implosion systems than of gun-type devices. [redacted] DOE b(3)

2.38 The effect of increasing compression in a simple (unboosted) implosion system is indicated by the data in Table 2.1 which are based partly on experimental observations and

Table 2.1 — EFFECT OF COMPRESSION ON EFFICIENCY

Average Compression Core	Average Compression Tamper	Efficiency (Percent)
[redacted]	[redacted]	[redacted]

DOE b(3)

partly on calculation. [redacted] DOE b(3) The attainment of high compression has been an important objective in fission weapon design. In the earliest (solid-core) devices the improvement in efficiency was the main purpose. In more recent (hollow-core boosted) weapons, however, the principal objective is to make possible the design of compact systems in which both the high explosive (§1.42) and the fissile material have low masses. The number of crits at maximum compression is not large, so that α is relatively small before boosting. The initial efficiency of the fission chain is, therefore, also small but the total yield is greatly increased by the boosting.

INITIATION TIME AND PREINITIATION

Unboosted Implosion Weapons

2.39 The time at which the fission chain is initiated is of importance in determining the efficiency of a weapon. [redacted] DOE b(3) By this time the fissile core would be highly supercritical. [redacted] DOE b(3)

2.48 As a result of spontaneous fission, uranium-235 emits, on the average about 0.85 neutron per kilogram per sec, whereas uranium-238 produces roughly 17 neutrons/kg-sec. Consequently, the neutron background in ordinary oralloy (93.5 weight percent uranium-235) is approximately 2 neutrons/kg-sec. [redacted]

DOE b(3)

DOE b(3)

It is seen, therefore, that a conventional gun-type weapon, based on plutonium with assembly brought about by a propellant explosive, is completely out of the question. It was the realization of this fact, when plutonium became available, that led to the development of implosion systems (§1.39).

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AN INTRODUCTION TO NUCLEAR WEAPONS (u)

By
Samuel Glasstone

December 1962
[DTI Issuance Date]

University of California, Los Alamos Scientific Laboratory

and

University of California, Lawrence Radiation Laboratory, Livermore

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FOREWORD

While this document has been published as a Headquarters, U. S. Atomic Energy Commission publication, it has as its genesis two 1954 Los Alamos Scientific Laboratory reports identified as LAMS-1632 and LAMS-1633, titled "Weapons Activities of LASL." These publications are well known and used extensively by those interested in nuclear weapons as basic handbooks on the principles of nuclear weapons development and technology. Dr. Samuel Glasstone has revised and consolidated the above reports incorporating information furnished by the Los Alamos Scientific Laboratory, Lawrence Radiation Laboratory—Livermore, The Sandia Corporation, and the Defense Atomic Support Agency.

This document has been prepared solely for reference purposes on the principles of atomic weapons development and should not be considered as a technical guide for designing nuclear weapons.

Since this issue contains highly sensitive atomic weapons information of significance to our national defense and security, all viewers are enjoined to insure its proper security protection at all times.

A. W. Betts
Major General, USA
Director of Military Application
U. S. Atomic Energy Commission

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In preparing this report, I have received invaluable assistance from members of the Lawrence Radiation Laboratory (Livermore), Los Alamos Scientific Laboratory, Defense Atomic Support Agency (Headquarters and Field Command), the Sandia Corporation, and the AEC Division of Military Application. Unfortunately, it is not possible to list the names of all those individuals who contributed either by providing information or by reviewing the draft manuscript or both. However, I wish to acknowledge my great indebtedness to them, for without their help this report could not have been produced. My special thanks are due to Lawrence S. Germain for his effective coordination of the contributions from LRL, Livermore.

S. G.

1.54 Uranium-238 nuclei capture slow neutrons quite readily to form a higher isotope, uranium-239, with the emission of gamma radiation; thus, the (n, γ) reaction

$$_{92}U^{238} + {}_0n^1 \rightarrow {}_{92}U^{239} + \gamma$$

occurs, where the subscripts give the atomic numbers and the superscripts the mass numbers in each case; the neutron ($_0n^1$) has a charge (atomic number) of zero and a mass of unity. The uranium-239 produced by neutron capture is radioactive, with a half-life of 23 min, emitting a beta particle. Representing the latter by $_{-1}\beta^0$, since it carries a unit negative charge and has essentially no mass, the radioactive decay process may be written as

$$_{92}U^{239} \rightarrow {}_{-1}\beta^0 + {}_{93}Np^{239}$$

the product being an isotope of mass number 239 of an element of atomic number 93. This element, called neptunium (Np), is virtually nonexistent in nature. DOE b(3)

1.55 Neptunium-239 is also radioactive with a half-life of 2.3 days; it emits a beta particle according to the reaction

$$_{93}Np^{239} \rightarrow {}_{-1}\beta^0 + {}_{94}Pu^{239}$$

so that the product has a mass number of 239 and an atomic number of 94. The name plutonium, symbol Pu, has been given to the element with this atomic number. The isotope plutonium-239 is an alpha-particle emitter with a fairly long half life—about 24,000 years—so that it is relatively stable. It may be mentioned that the decay product of plutonium-239 is the fissile uranium-235, which has a half-life of about 9×10^8 years. Hence, as far as fission is concerned, plutonium-239 could be stored for thousands of years with only minor deterioration. The little deterioration which does occur arises mainly from the fact that the average number of neutrons, ν, produced by fission of uranium-235 is somewhat less than that from plutonium-239 (§1.12).

1.56 For the production of plutonium-239, natural uranium metal is used as the fuel material in a nuclear reactor with graphite (Hanford) or heavy water (Savannah River) as the moderator. The uranium-235 in the fuel sustains the fission chain reaction and produces neutrons, some of which are captured by the uranium-238 with the consequent formation of plutonium-239, as described above. After being in the reactor for an appropriate time, the "spent" fuel is removed, dissolved in nitric acid, and the plutonium is extracted from the solution by the use of certain organic solvents. It is then re-extracted into a water medium to give an aqueous solution of the nitrate, from which the plutonium is precipitated either as the peroxide or the oxalate. The solid compound is separated and heated with a mixture of hydrogen fluoride gas and oxygen to obtain plutonium tetrafluoride (PuF_4). The latter is finally reduced to plutonium metal with calcium (plus iodine).

1.57 Metallic plutonium exists in six different allotropic forms between room temperature and the melting point (640°C). The temperature ranges over which the various forms (or phases) are stable are shown in Table 1.3. It is seen that alpha-plutonium, referred to in §§1.23 and 1.34, which has a density of 19.6 g/cm^3, is stable at ordinary temperatures. The high density is advantageous from certain weapon standpoints, since it permits attainment of criticality in a smaller mass than is possible with other forms of plutonium (cf. Table 1.2). On the other hand, alpha-plutonium is brittle and difficult to fabricate. Furthermore, the presence of certain impurities retards the attainment of the alpha-phase equilibrium, so that fabricated parts exhibit dimensional instability. However, if these impurities are avoided, the dimensional instability problem does not arise.

1.58 Although delta-plutonium is normally stable in the temperature range of 319 to 451°C, the addition of 1 weight percent of gallium to plutonium stabilizes the delta phase at or-

dinary temperatures. The plutonium used in most stockpile weapons is in the stabilized delta form. The material is much less brittle and easier to fabricate than alpha-plutonium: in fact delta-plutonium is said to resemble aluminum in this respect whereas the alpha-phase is more like cast iron. Delta-plutonium was used in the earliest implosion weapons because its low density permitted the use of a larger mass of subcritical fissile material (Table 1.2), thereby making possible an increase in the total energy yield. This aspect of weapons design is, however, no longer significant.

Table 1.3 — Properties of Solid Phases of Plutonium

Phase	Stability range	Density (g/cm^3)
Alpha (α)	Up to 120°C	19.6 (25°C)
Beta (β)	120 to 206°C	17.8 (150°C)
Gamma (γ)	206 to 319°C	17.2 (210°C)
Delta (δ)	319 to 451°C	15.9 (320°C)
Delta prime (δ')	451 to 476°C	16.0 (465°C)
Epsilon (ϵ)	476 to 640°C (m.p.)	16.5 (510°C)

Plutonium-240

1.59 As the plutonium-239 accumulates in the reactor in which it is produced, it also captures neutrons, the rate of capture being proportional to the neutron density (or flux) in the reactor and to the concentration of plutonium-239 nuclei. The reaction which takes place is

$$_{94}Pu^{239} + {_0}n^1 \rightarrow {_{94}}Pu^{240} + \gamma$$

the product being plutonium-240, an alpha emitter of about 6600 years half-life. The two isotopes of plutonium are not separated from one another in the chemical process used for the extraction of this element from the reactor fuel. Hence, plutonium-239 is always associated with a certain proportion of plutonium-240, the amount of the latter increasing, with both the exposure time and neutron density in the reactor, up to a limiting value of about 35 percent.

1.60 In a simple (unboosted) implosion type weapon, it is desirable that the plutonium-240 content be as small as possible for two reasons: (a) the high spontaneous fission rate of plutonium-240 causes a large neutron background (§1.37) which can result in the initiation of a fission chain before the optimum time, and (b) the fission of plutonium-240 requires mostly neutrons of high energy and, in addition, the ν value is smaller than for plutonium-239 so that it acts, to some extent, as an inert diluent.* Consequently, if plutonium-240 is present, the mass of plutonium-239 required for criticality is larger than would be the case for pure material (§1.23). [redacted] DOE b(3)

It should be noted that to obtain a product with a small proportion of plutonium-240, the uranium fuel elements can be permitted to remain in the reactor for only a short time before they are removed and processed for the extraction of plutonium. As a result, the smaller the plutonium-240 content, the higher the cost of the material produced.

1.61 In evaluating the cost of the plutonium in a weapon, it must be recognized that the higher the plutonium-240 content the smaller the cost per unit mass of plutonium-239, but the larger the mass required for criticality. The actual cost per crit, which is the important cri-

*Fission of plutonium-240 exhibits an appreciable resonance for neutrons of about 1-ev energy. Otherwise, the cross sections are low except at high neutron energies.

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CHAPTER 2

THE FISSION PROCESS IN WEAPONS

INCREASE OF NEUTRON POPULATION

The Multiplication Rate: Alpha

2.1 No matter how it originates, an explosion is associated with the very rapid liberation of a large amount of energy within a restricted space. If the energy is to be produced by fission, then an essential condition for explosion is a very high neutron density, since the rate of fission, and hence the rate of energy release, is proportional to the number of neutrons per unit volume. It is of interest, therefore, to examine the factors which lead to a high neutron density, since these will form a basis for fission weapon design.

2.2 In accordance with the definition of the effective multiplication factor, k, given in §1.19, it follows that for every n neutrons present at the beginning of a generation there will be nk neutrons at the beginning of the next generation, so that the gain of neutrons is $n(k-1)$ per generation. The rate of gain, dn/dt, may then be obtained upon dividing the actual gain by the average time, τ, between successive fission generations; hence,

$$\frac{dn}{dt} = \frac{n(k-1)}{\tau} \tag{2.1}$$

Equation (2.1) will be strictly correct only if delayed neutrons play no part in maintaining the fission chain. As already stated (§1.13), this condition is applicable, to a good approximation, to nuclear fission weapons.

2.3 The quantity $k - 1$, which is the excess number of available neutrons per fission, may be represented by x, i.e.,

$$x \equiv k - 1 \tag{2.2}$$

and then equation (2.1) becomes

$$\frac{dn}{dt} = \frac{x}{\tau} n \tag{2.3}$$

The time rate of increase (or decrease) in neutron population can be expressed in the general form

$$\frac{dn}{dt} = \alpha n \tag{2.4}$$

where α is the specific rate constant for the process which is responsible for the change in the number of neutrons. In nuclear weapons work this constant is called the multiplication rate or merely "alpha." Comparison of equations (2.3) and (2.4) shows that for a fission chain reaction

$$\alpha = \frac{x}{\tau} \tag{2.5}$$

2.4 The foregoing results are applicable regardless of whether x, and hence α, is positive, zero, or negative. For a subcritical system, $k < 1$ (§1.20), i.e., $k - 1$ is negative; in these circumstances x is negative and so also is α. It follows from equation (2.4) that dn/dt is then negative and the number of neutrons in the system will decrease with time. Consequently, in agreement with previous conclusions, the fission chain in a subcritical system will eventually die out because of the steady decrease in the neutron population. When the system is just critical, $k = 1$, and x and α are both zero; the number of neutrons will thus remain constant. Finally, for a supercritical system, $k > 1$, and x and α are positive; there will then be a steady increase in the neutron population. Since dn/dt is proportional to n, by equation (2.4), it is evident that in a supercritical system, the number of neutrons will grow at increasingly faster rates as n increases.

2.5 Another aspect of the significance of α becomes apparent when equation (2.4) is written in the form

$$\frac{dn}{n} = \alpha \, dt$$

If α is assumed to remain constant, this expression can be readily integrated between the time limits of zero, when the number of neutrons present is n_0, and t, when the number is n. The result is

$$n = n_0 e^{\alpha t} \tag{2.6}$$

where, as usual, e is the base of natural logarithms. This expression, like those given above, is applicable regardless of whether α is positive, zero, or negative. If α is known, equation (2.6) can be used to calculate the neutron population at any time t relative to the value at any arbitrary zero time. It can also be seen from equation (2.6) that $1/\alpha$ is the time period during which the number of neutrons changes by a factor e; consequently, $1/\alpha$ is often referred to as the e-folding time, i.e., the time in which there is an e-fold change in the neutron population.

Determination of Alpha

2.6 The value of α is a highly important quantity in weapons design, as will shortly be apparent. Attempts are made to estimate it theoretically from the neutronic and hydrodynamic characteristics of the system, but there are many uncertainties involved and experimental measurements are desirable. In weapons tests, the determination of alpha is one of the most important diagnostic requirements. The methods used under these circumstances are described in Chapter 8. The present treatment will be restricted to procedures which can be used in the design phase without an actual test of the weapon.

2.7 Since a supercritical (or even a critical) mass cannot be handled safely under ordinary conditions, experimental measurements of α are made with a mass that is slightly subcritical. Into this assembly is injected a burst of neutrons and these neutrons initiate a large number of chains. However, since the system is subcritical, α will be negative and so the number of neutrons will decrease after the initial increase. By determining a quantity proportional to the neutron population as a function of time, with neutron counters located outside the assembly, it is possible to determine α by means of equation (2.6). The α obtained from the decrease in neutron population in the early stages is the so-called prompt value, required for weapons studies in which the delayed neutrons play no part.

2.13 The fission mean free path is equal to $1/N\sigma_f$, where N is the number of fissile nuclei per cm^3 and σ_f is the fission cross section.* Hence, from equation (2.8),

$$\tau \approx \frac{1}{N\sigma_f v} \tag{2.9}$$

so that the generation time is inversely proportional to the produce $\sigma_f v$. The value of σ_f decreases as v increases but the product is 2×10^9 (in 10^{-24} cm^3/sec units) for fast neutrons of 1-Mev energy compared with 10^8 for slow neutrons. Hence, the fission generation time is appreciably shorter for fast than for slow neutrons. Actually, the situation is worse for slow neutrons than would appear from a comparison of the values of $\sigma_f v$ because the effective generation time for these neutrons includes the slowing-down time and this is considerably longer than $\sigma_f v$ alone would indicate.

2.14 From the information already given, it is possible to make a rough, order-of-magnitude estimate of α. As seen from Table 1.1, ν is about 2.5 to 3; the loss, l, of neutrons per fission may be taken as 0.5 to 1, and so, by equation (2.2), x is close to unity for a highly supercritical system. For uncompressed uranium-235 or plutonium-239, the number, N, of nuclei per cm^3 is roughly 0.5×10^{23} and, as seen above, $\sigma_f v$ for fast-neutron fission is $2 \times 10^9 \times 10^{-24}$ cm^3/sec. It follows, therefore, from equation (2.7) and (2.9) that

$$\alpha \approx (0.5 \times 10^{23})(2 \times 10^{-15}) \approx 10^8 \text{ sec}^{-1}$$

Thus, for fast-neutron fission, α is about 10^8 sec^{-1} in a supercritical system and τ, the generation time, is roughly 10^{-8} sec (or 1 shake). It is the common practice to express values of α in reciprocal shakes, i.e., 10^8 sec^{-1} units, so that in the rough calculation made above α is approximately 1 $shake^{-1}$. Experimental measurements, both in the laboratory and at weapons tests, show that α is indeed of this order of magnitude.†

2.15 It is evident that in order to achieve an efficient nuclear explosion, fission should be brought about by fast neutrons, as far as possible. For such neutrons, the factors ν and τ, and to some extent l, favor a high value of α and, hence, a rapid increase in the neutron population. Except in certain special cases, appreciable amounts of elements of low mass number, which slow down neutrons, are consequently kept out of the core of a fission weapon.

2.16 According to equation (2.9), the fission generation time for neutrons of a given energy (or velocity) is inversely proportional to the number, N, of fissile nuclei per cm^3. It follows, therefore, that τ is inversely proportional to η, the core compression ratio; thus

$$\tau \propto \frac{1}{\eta} \tag{2.10}$$

Consequently, the generation time can be decreased, and the value of α increased, by compression of the core material.

2.17 In addition to the effect on τ, compression also causes a marked decrease in l, for the reason given in §1.40. This also contributes to an increase in α, as follows from equation (2.7). It is seen, therefore, that compression of the core will cause an increase in α because of the decrease in both τ and l.

Explosion Time

2.18 According to the arguments in §2.14, x is approximately equal to unity and so, by equation (2.5), $1/\alpha$ is roughly equal to τ, the generation time. It is thus possible to write equation (2.6) in the approximate form

---

*For the present purpose it is sufficient to regard the cross section as the effective area in sq cm of a nucleus for a particular reaction (or reactions). Cross sections vary with the neutron energy and the fission cross sections for uranium-235 and plutonium-239 have been measured over a large energy range.

†Some workers prefer to express α in reciprocal microseconds.

efficiencies were estimated by the method of Bethe and Feynman. The basic formula is admittedly approximate, since it involves several simplifying assumptions. However, its derivation is useful in the respect that it provides a model of the explosion of a fission weapon and indicates, qualitatively at least, some of the factors which affect the efficiency of the explosion. The treatment given below is applicable to pure fission systems and not after boosting occurs.

2.29 As a result of the energy liberated in fission, very large pressures (~10^9 atm) are developed in the core, and the core-tamper interface consequently receives a large outward acceleration. This causes highly compressed tamper material to pile up just ahead of the expanding interface, in an effect referred to as the "snowplow" phenomenon, because of the similarity to the piling up of snow in front of a snowplow. The inertia of the compressed tamper delays expansion of the core, so that a considerable pressure gradient builds up from the center of the core to its outer surface.

2.30 Furthermore, because of the delayed expansion, it may be supposed that the volume of the compressed (supercritical) core remains essentially constant during the first [redacted] DOE b(3) so generations following initiation of the fission chain, i.e., up to explosion time. After this interval, almost the whole of the energy is released within an extremely short period, during which time the supercritical core expands rapidly until it becomes subcritical. Although there is an appreciable release of energy even while the system is subcritical, as mentioned in §2.27, it will be postulated that energy production ceases when the dimensions are just critical. It will be assumed, further, that no energy escapes during the short period of expansion from maximum supercriticality to the point where the system becomes subcritical.

2.31 Let R be the radius of a spherical core at the point of maximum supercriticality; then, in accordance with the postulate made above, this will remain unchanged until explosion time. Subsequently, the energy density of the system becomes so large that mechanical effects begin and the core starts to expand. Suppose that when the core has expanded by a fraction δ, so that the radius is $R(1 + \delta)$, the system is just critical (Fig. 2.1); beyond this point it will be subcritical. The self-sustaining fission chain will then end and, in accordance with the approximation postulated above, there will be no further release of energy.

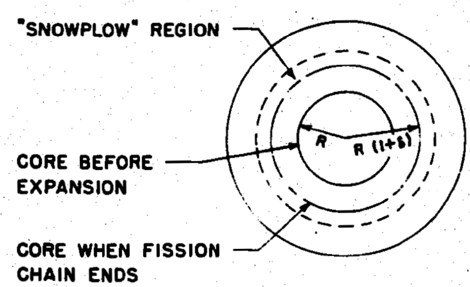

Figure 2.1

2.32 Consider a thin shell of material in the core, of volume dV and thickness dR; the cross sectional area of the shell is then dV/dR. If dP is the pressure difference on the two sides of this shell, caused by the liberated fission energy, the net outward force, dF, to which the shell is subjected, i.e., pressure × area, is then

$$dF = dP\frac{dV}{dR} = \frac{dP}{dR}dV \tag{2.14}$$

where dP/dR is the pressure gradient in the given shell. As a reasonable approximation, it may be supposed that the pressure gradient is essentially constant across the core radius, so that

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[redacted]

$$\frac{dP}{dR} \approx \frac{P}{R} \tag{2.15}$$

where P is the total difference in pressure from the center of the core to the outer surface before expansion occurs. Hence, from equations (2.14) and (2.15),

$$dF \approx \frac{P}{R} dV \tag{2.16}$$

2.33 The time required for the core to expand from radius R to R(1 + δ), i.e., a distance of Rδ, is about 7 generations, as seen in §2.21. However, as a rough approximation, this may be taken as $1/\alpha$, where α is the multiplication rate just prior to explosion time. The mean outward acceleration of the core material, and of the shell dV, may consequently be expressed as $R\delta\alpha^2$. The mass of the shell is ρdV, where ρ is the core density; hence, by Newton's second law of motion, i.e., force = mass × acceleration, the force dF acting on the shell is given by

$$dF \approx \rho dV \times R\delta\alpha^2$$

Upon comparing this result with equation (2.16), it is seen that

$$P \approx \rho R^2 \alpha^2 \delta \tag{2.17}$$

2.34 At the existing temperature the core will be gaseous and if, as postulated, the loss of energy from the system during the initial expansion is negligible, it may be considered as a gas undergoing an adiabatic process. The total energy of such a gas, which may be taken to be equal to the energy of the core, is then

$$E = \frac{PV}{\gamma - 1} \tag{2.18}$$

where γ is the ratio of the specific heats of the gas. Using equation (2.17) for P and writing M/ρ for the volume of the core, M being the mass, equation (2.18) becomes

$$E \approx \frac{MR^2\alpha^2\delta}{\gamma - 1} \tag{2.19}$$

2.35 If ϵ is the energy released in the complete fission of unit mass of core material, then the total energy available in the core is $M\epsilon$, and the efficiency, according to equation (2.13), is $E/M\epsilon$, where E is given by equation (2.19); consequently,

$$\phi = \frac{E}{M\epsilon} \approx \frac{R^2\alpha^2\delta}{(\gamma - 1)\epsilon} \tag{2.20}$$

It should be pointed out that in the foregoing derivation no allowance has been made for depletion of the core material as fission proceeds. For low efficiencies, to which most of the other approximations made are applicable, the depletion is not significant and can be neglected. Moreover, no allowance has been made for the inertial effect of the tamper on the efficiency. For the present purpose, which is to obtain a qualitative guide to some of the factors determining the efficiency, this can also be ignored. Hence, replacing the quantity $1/(\gamma - 1)\epsilon$ by a constant, K, equation (2.20) can be written as

$$\phi \approx KR^2\alpha^2\delta \tag{2.21}$$

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2.40 The avoidance of preinitiation was therefore an important aspect of the design of simple fission weapons. The neutron sources which served as initiators were constructed so as to produce a burst of neutrons as close as possible to the optimum time, and the neutron background from the fissile material was maintained within reasonable bounds. In all-plutonium cores, relatively clean (20 ngs) material was used and dirtier plutonium was employed only in composite cores which contained oralloy in addition, with the latter in excess. Such a utilization of fissile material was desirable in any event, for reasons given in §3.21 et seq.

2.41 The behavior of the solid core in an unboosted implosion weapon is somewhat as follows. DOE b(3) [redacted] At first critical, α is zero and it increases steadily as compression of the core proceeds. Just before maximum compression, when α is approaching its maximum value, neutrons are injected into the highly supercritical system. The divergent fission chain is initiated and energy is released. DOE b(3) [redacted] DOE b(3) This condition is referred to as "second critical" (Fig. 2.2). Both the neutron density and the rate of the fission reaction are now at a maximum. Beyond second critical, α becomes negative and the neutron density decreases, in accordance with equation (2.6). Although a self-sustaining chain is no longer possible, considerable amounts of energy are produced by the convergent fission chains in the subcritical system.

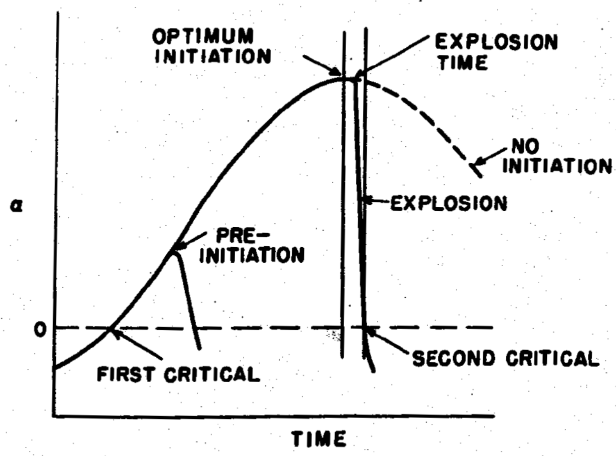

Figure 2.2

Boosted Implosion Systems

2.42 In modern boosted, implosion-type fission weapons, the situation is quite different from that described above. The cores are hollow, subcritical shells which contain the deuterium-tritium boosting gas. [redacted] DOE b(3)

[redacted]

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Gun-Type Weapons

2.45 In a gun-type weapon, the lack of compression makes it desirable for initiation to take place at or close to the time when assembly [redacted]

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Consequently, although plutonium-239 with an appreciable proportion of plutonium-240 could be used in implosion systems, even of the solid-core, unboosted type, it is unsuitable for gun-assembly devices, as the calculations given below will show.

2.46 Apart from the possible presence of a "flood" of neutrons, e.g., as the result of the explosion of another nuclear weapon in the vicinity of a given weapon, the chief sources of background neutrons, which could cause preinitiation in a gun-assembly weapon, are spontaneous fission and (α,n) reactions with light elements. In uranium-235 (oralloy) the rate of spontaneous fission is relatively small but (α,n) reactions with light-element impurities could produce an appreciable neutron background. [redacted]

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2.47 Let P_1 be the probability that a background neutron will be available in the fissile material during the period that it is supercritical, i.e., in the preinitiation period, and let P_2 be the probability that this neutron will be able to start a fission chain. The preinitiation probability, P, is then given by

$$P = 1 - e^{P_1 P_2}$$

$$\approx P_1 P_2 \qquad (2.22)$$

the approximate form being applicable when P_1P_2 is small, as it is in cases of interest. Actually P_2 is a function of time and both P_1 and P_2 depend, to some extent, on the position of the neutron and on other factors. For the present purpose, however, which is to draw general conclusions only, specific values will be assigned to P_1 and P_2. A background neutron entering a fissile assembly may escape altogether without being absorbed, or it may be captured in a nonfission reaction, or it may initiate a fission chain. Although the probabilities of these three processes are by no means equal, it is sufficient to postulate here that P_2 has a constant average value of 0.3 over the preinitiation period. Hence, for the purpose of making rough estimates, equation (2.22) may be written as

$$P \approx 0.3\, P_1 \qquad (2.23)$$

[redacted]

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WASH-1038 Revised

This document consists of 128 pages.

Classified by Ralph G. Shull
Chief, Liaison Branch
Division of Military Application

AN INTRODUCTION TO NUCLEAR WEAPONS

By Samuel Glasstone and
Leslie M. Redman

June 1972

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Refer all requests

FOREWORD

While this revision of WASH-1038 and the original issuance have been published as Headquarters, U. S. Atomic Energy Commission documents, they have as their genesis two 1954 Los Alamos Scientific Laboratory reports, LA 1632 and LA 1633, both entitled "Weapons Activities of LASL." We are indebted to LASL for these early reports. Although the previous LA and WASH reports received extensive use as basic handbooks on the principles of nuclear weapons development and technology, they were not to be considered as technical guides for designing weapons. Similarly, this revision of WASH-1038 is not to serve as such a guide.

In the preparation of this document, Dr. Samuel Glasstone has reviewed, coordinated, and edited data provided by members of the Los Alamos Scientific Laboratory, the Lawrence Livermore Laboratory, the Sandia Laboratories, and the Defense Nuclear Agency. The exceptional cooperation of these organizations and the outstanding work of Dr. Glasstone have permitted the Atomic Energy Commission to publish this revision to WASH-1038. Further, we wish to recognize the very significant contributions of Dr. Leslie M. Redman in the preparation of this issuance.

This publication contains highly sensitive nuclear weapon design information of significance to our national defense and security. Viewers are enjoined to ensure its proper security protection at all times.

Edward B. Giller

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for Military Application
U. S. Atomic Energy Commission

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[redacted] for fast-neutron fission are given in Table 1.2. Values are quoted for bare, i.e., untamped spheres, as well as for spheres with tampers of [redacted]

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[redacted] The name gun-type originates from the fact that in devices of this kind the two pieces of fissile material, [redacted] are located near opposite ends of a gun barrel.*

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Table 1.2 CRITICAL MASSES OF SPHERES

Fissile Material	^{240}Pu (wt %)	Density (g/cm^3)	Critical mass (kg)				
			Bare	[redacted] U	U	Be	Be
Uranium-235 (93.2 wt %)		18.8	52.5	[redacted]			
Plutonium-239 (α)	4.8	19.7	10.5				
Plutonium-239 (δ)*	4.8	15.8	16.6				
Plutonium-239 (δ)*	21	15.8	18.8				
[redacted]							

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*Contains ~1 wt % gallium. [redacted] DOE b(3)

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[redacted] beryllium, respectively. The effect of the neutronic tamper in reducing the critical mass is very striking. It will be noted, too, in accordance with remarks made earlier, that the critical mass of delta-plutonium is larger than that of the alpha form, whereas both are smaller than the critical mass of uranium-235.

FISSION WEAPONS

Gun Method of Assembly

1.35 As long as a mass of fissile material is less than the critical value for the existing conditions, that is to say, provided the system is subcritical, there is no danger of a divergent, or even a stationary, chain reaction. But, if energy is to be released in a nuclear explosion, the system must be made critical and, in fact, highly supercritical, as will be seen shortly. There are two general ways utilized in weapons whereby a subcritical system of fissile material is rapidly converted into one that is supercritical.

1.36 The first is generally referred to as the gun method of assembly. Two portions of material of subcritical size are brought together very rapidly, for reasons given below, so that the combined mass is supercritical. If a burst of neutrons is then introduced, a divergent fission chain is initiated and a rapid release of energy occurs in a very short time. This is the principle used in the so-called "gun-type" weapons: [redacted]

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1.37 Although the gun assembly method for attaining criticality is satisfactory when uranium-235 is the fissile material, it has a serious drawback when plutonium-239 is used. This arises from the presence of the higher isotope, plutonium-240. Because of the way it is produced (§1.53), plutonium-239 is invariably associated with a certain proportion—generally from about 2 to 7 percent—of the higher isotope, plutonium-240. The latter happens to have a high probability for undergoing spontaneous fission, i.e., without the intervention of neutrons. The spontaneous fission rate of plutonium-240 is, in fact, about 440 fissions per second per gram. Since more than two neutrons are liberated per fission, on the average, this means that 1 gram of plutonium-240 emits over 1000 neutrons per second. [redacted]

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1.38 An efficient use of the fissile material in a simple gun-type weapon requires that the chain reaction be initiated by neutrons only when the assembly has attained its maximum criticality. [redacted] the considerable neutron background, arising from the presence of plutonium-240, may result in initiation of a self-sustaining chain reaction as soon as the assembly becomes just critical. If this occurs, there will be little

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*It is purely a coincidence that in most nuclear artillery shells the gun type of assembly is used [redacted]here is, however, another type of artillery shell which does not employ gun assembly (§4.23).

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or no explosion, since the neutron density will not increase rapidly and energy, resulting from fission, will not be produced fast enough; the reasons for such behavior will be apparent later. On the other hand, uranium-235 has a small neutron background and therefore can be used in a gun-type weapon. If assembled rapidly enough, there is little probability of premature initiation, or "preinitiation," as it is called, immediately upon the system becoming critical. When maximum supercriticality is attained, neutrons are introduced deliberately from a suitable source to initiate the fission chain reaction. In this way, the optimum efficiency can be realized in the use of the fissile material.

Compression Method (Implosion Weapon)

1.39 Because of the probability of preinitiation, and low efficiency, of a gun-assembly weapon using plutonium-239, an alternative method for attaining criticality (or supercriticality) was developed, based on the compression of the subcritical fissile mass. This procedure turned out to be so successful and gave so much better efficiency that the gun type of assembly has been utilized only in a relatively few weapons for special purposes, e.g., in artillery-fired shells and in rugged, impact-resistant bombs designed to penetrate some distance into the ground before exploding. Apart from these particular cases, the compression method is invariably used to attain supercriticality in fission weapons.

1.40 The principle of the method is that if a mass of fissile material is compressed, the rate of production of neutrons by fission in the subcritical state is essentially unchanged, since it depends mainly on the number of nuclei present. Actually, there will be some increase in the neutron production in convergent chains. On the other hand, the number of neutrons lost by escape is decreased as a result of compression because of the smaller surface area of the given mass. Consequently, a quantity of material which is subcritical in the normal state can become supercritical when compressed. The introduction of neutrons to initiate the fission chain at (or close to) the time of maximum compression—and, hence, of maximum supercriticality—results in an efficient use of the fissile material in causing an explosion.

1.41 In practice, the compression occurs very rapidly, [redacted]

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[redacted]

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1.42 The compression in these weapons is achieved by the use of a powerful conventional (chemical) high explosive which surrounds the core of fissile material. By the use of explosive charges of special design much of the energy of the explosion is directed inward, thereby causing the material in the interior to be compressed in a spherically symmetric manner. It is for this reason that the term "implosion" is applied to weapons of this type.

1.43 An approximate derivation of the relationship between the degree of compression and the critical mass of fissile material is the following.† The total mean free path of a neutron is the average distance it travels before it interacts in any way with a nucleus. The proportion of neutrons which do not interact but escape from the system may be expected to be determined by the ratio of the dimensions, e.g., the radius of a sphere, to the mean free path. It may be concluded, therefore, that for a given fissile (core) material, under specified conditions, the critical radius should be approximately proportional to the neutron mean free path; thus, if R_c is the critical radius and λ is the mean free path in the material,

$$R_c \propto \lambda. \tag{1.6}$$

1.44 The greater the probability of the interaction of a neutron with a nucleus, the smaller will be the distance the neutron travels before interacting. Hence, the neutron mean free path is related inversely to its interaction probability. This probability is proportional to the number of fissile nuclei per unit volume, and hence to the density; if ρ is the density of the core material, then

$$\lambda \propto \frac{1}{\rho}. \tag{1.7}$$

[redacted]

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†The purpose of the discussion in §1.43 through §1.47 is to provide a general basis for understanding the effect of compression on criticality. It is not intended to imply that the methods are currently used. At present, computer calculations, which can take many variables into consideration, are employed to derive criticality conditions. The term "crit" in §1.46 is now more or less obsolete in weapons calculations.

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[redacted] If the plutonium were to be used in the alpha phase, however, the presence of a relatively large proportion of plutonium-241, which would decay to americium-241, could lead to a phase change to the delta form. The accompanying decrease in density would then result in dimensional instabilities. To test this point, a sample of alpha-plutonium containing 12.3 percent of plutonium-241 has been under observation since February 1964. A decrease in density from 19 to about 17.8 g/cm^3 occurred between 56 and 64 months, when the americium content was roughly 2.7 weight percent, but x-ray examination showed that the material still consisted entirely of the alpha phase. The significance of the results is uncertain and the observations are being continued.

Composition of Weapons Plutonium

1.69 In addition to plutonium-239 and -240, which are the main components, weapons-grade plutonium contains small quantities of isotopes of both higher and lower mass numbers. These are produced in a reactor by various neutron reactions either $(n,2n)$ or (n,γ). The average isotopic compositions of plutonium from Hanford and Savannah River plants reported in June 1968 are quoted in Table 1.5; these may be regarded as typical of current production.

Table 1.5 COMPOSITION OF WEAPONS-GRADE PLUTONIUM IN WEIGHT PERCENT

	Hanford	Savannah River
Plutonium-238	<0.05	<0.05
Plutonium-239	93.17	92.99
Plutonium-240	6.28	6.13
Plutonium-241	0.54	0.86
Plutonium-242	<0.05	<0.05

Possible Weapons Materials

1.70 Several fissile nuclides, with atomic number exceeding 94, are known, but they are of no practical value for weapons purposes because of their short half-lives. A region of stability has been predicted, theoretically, however, for very heavy species in the vicinity of those having "magic numbers" of both protons and neutrons, e.g., 114 protons and 184 neutrons, i.e., $^{298}_{114}X$, and 126 protons and 184 neutrons, i.e., $^{310}_{126}X$. Such nuclides might have half-lives up to 10^6 to 10^8 years, and would be expected to be capable of sustaining a fission chain with [redacted]

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[redacted]

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Production of Neutrons

1.73 In a fission weapon, the chain reaction is initiated by the introduction of neutrons into a critical or supercritical system. Consequently, the general methods for producing neutrons in weapons will be reviewed here. One of the simplest procedures for obtaining neutrons is by the action of alpha particles on certain light elements, notably beryllium; processes of this kind are referred to as (α,n) reactions. Recalling that the alpha particle is actually a helium nucleus, the reaction is represented by

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{12}_{6}C + ^{1}_{0}n.$$

1.74 A convenient source of alpha particles, which was used extensively at one time in fission weapons, is

"incubation time" (Fig. 2.1). The time between first critical and explosion (or maximum supercriticality) is here called the "assembly time."*

2.24 Because of the rapid increase in the neutron population during the propagation of the fission chain reaction, the fission energy is released at a very high rate. The heat generated causes the temperature to increase and the fissile material expands (or disassembles) rapidly. Soon the volume becomes so large that the system becomes subcritical and the divergent chain reaction ceases. The point at which the material passes through the critical stage during expansion is called "second critical" (§ 2.59).

2.25 The number of fission generations corresponding to the explosion time for a spherical (imploded) core can be calculated in a semiquantitative way in the following manner.† If the reasonable assumption is made that the pressure in the assembly has a parabolic distribution, then the pressure P at a distance r from the center of the core of radius R is

$$P = P_0\left(1 - \frac{r^2}{R^2}\right), \qquad (2.11)$$

where P_0 is the pressure at the center. If $\bar{P}$ is the average pressure in the core then, as shown in the appendix to this chapter,

$$\bar{P} = \frac{1}{5}\rho R a, \qquad (2.12)$$

where ρ is the density of the core material and a is the acceleration at its surface.

2.26 If the change in velocity at the surface of the core at a time t after initiation of the chain reaction is represented by Δv, then

$$\Delta v = \int_0^t a\,dt. \qquad (2.13)$$

Furthermore, with an exponentially increasing neutron population, as indicated by equation (2.6), the acceleration, as well as the energy density and the pressure, will vary as $e^{\alpha t}$; hence,

$$a = Ae^{\alpha t},$$

where A is a constant. If this result is substituted into equation (2.13), it is seen that

$$\Delta v = \frac{a}{\alpha}. \qquad (2.14)$$

2.27 Suppose the unperturbed velocity of the core surface during assembly, i.e., before it is affected by the fission energy, is v_0; then the assembly motion will be halted when

$$\Delta v = v_0, \qquad (2.15)$$

and this corresponds to explosion time. Consequently, from equations (2.14) and (2.15), at explosion time

$$a = v_0\alpha,$$

and from equation (2.12)

$$\bar{P} = \frac{1}{5}\rho R v_0 \alpha. \qquad (2.16)$$

This is the average pressure in the core at explosion time.

2.28 The application of equation (2.16) may be illustrated by considering the hypothetical case of a core with a density, ρ, of 20 g/cm^3, and a radius, R, of 5 cm. The unperturbed rate of assembly, v_0, may be [redacted] and α is set at 1 gen/shake, i.e., 10^8 gen/sec. If these values are substituted into equation (2.16), it follows that at explosion time DOE b(3)

[redacted] DOE b(3)

2.29 At explosion time, the core will be effectively a gas at very high pressure and it may be considered to

*In weapons test, a measured time interval is that between firing the HE system and the first appearance of gamma rays from the explosion; it is called the "HE transit time" or simply the "transit time."

†The purpose of this treatment is merely to provide a general understanding of the core behavior. In weapons design studies, more exact calculations are made with the aid of computers.

‡The unit 1 bar is equivalent to a pressure of 10^6 dynes/cm^2; the megabar, i.e., 10^6 bars, is then 10^{12} dynes/cm^2. The standard atmospheric pressure (760 mm of mercury) is 1.013 bars; thus a pressure of 1 atm is approximately 1 bar.

2.43 It is of interest to mention, in passing, that the efficiency of the earliest implosion weapons was [redacted] the gun-type systems (§ 1.36). This accounts for the fact that devices of the latter type have occupied a secondary place in the development of fission weapons, except for special purposes.

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Calculation of Efficiency: Computer Methods

2.44 At the present time, the efficiency or, more correctly, the energy yield of a weapon is determined by computer calculations based on codes which have been developed to represent the behavior of the fission chain system. The calculations usually start at or immediately before explosion time, when significant mechanical effects may be assumed to begin. From initiation up to this time, the material is essentially stationary or is still being compressed and only a small proportion of the total energy has been liberated. The treatment takes into account the neutronic behavior, the hydrodynamics, and heat flow; the motion of a series of concentric shells (or "mass points") is followed until the rate of energy release by fission has fallen almost to zero. The total yield includes the energy released after the system has expanded and become subcritical. Although self-sustaining chain propagation is no longer possible, convergent-chain interaction of the many neutrons and fissile nuclei still present will result in considerable energy production. This may amount to some 30 percent or more of the total yield.

The Bethe–Feynman Formula

2.45 Prior to the development of computing machine procedures, and before data were available from test explosions for comparison and normalization purposes, fission weapon efficiencies were estimated by the method of Bethe and Feynman. The basic formula is admittedly approximate, since it involves several simplifying assumptions. However, its derivation is useful in the respect that it provides a model of the explosion of a fission weapon and indicates, qualitatively at least, some of the factors which affect the efficiency of the explosion. The treatment given below is applicable to pure fission systems and not after boosting occurs.

2.46 As a result of the energy liberated in fission, very large pressures (10–1000 megabars) are developed in the core, and the core-tamper interface consequently receives a large outward acceleration. This causes highly compressed tamper material to pile up just ahead of the expanding interface, in an effect referred to as the "snowplow" phenomenon, because of the similarity to the piling up of snow in front of a snowplow. The inertia of the compressed tamper delays expansion of the core, so that a considerable pressure gradient builds up from the center of the core to its outer surface.

2.47 Furthermore, because of the delayed expansion, it may be supposed that the volume of the compressed (supercritical) core remains essentially constant during the [redacted] or so generations following initiation of the fission chain, i.e., up to explosion time. After this interval, almost the whole of the energy is released within an extremely short period, during which time the supercritical core expands rapidly until it becomes subcritical. Although there is an appreciable release of energy even while the system is subcritical, as mentioned in § 2.44, it will be postulated that energy production ceases when the dimensions are just subcritical. It will be assumed, further, that no energy escapes during the short period of expansion from maximum supercriticality to the point where the system becomes subcritical. DOE b(3)

2.48 Let R be the radius of a spherical core at the point of maximum supercriticality; then, in accordance with the postulate made above, this will remain unchanged until explosion time. Subsequently, the energy density of the system becomes so large that mechanical effects begin and the core starts to expand. Suppose that when the core has expanded by a fraction δ, so that the radius is $R(1 + \delta)$, the system is just critical (Fig. 2.2); beyond this point it will be subcritical. The self-sustaining fission chain will then end and, in accordance with the approximation postulated above, there will be no further release of energy.

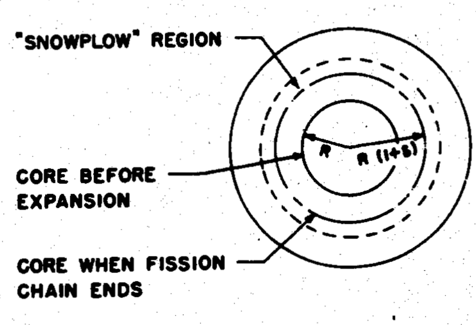

Figure 2.2

2.49 Consider a thin shell of material in the core, of volume dV and thickness dR; the cross sectional area of the shell is then dV/dR. If dP is the pressure difference on the two sides of this shell, caused by the liberated fission energy, the net outward force, dF, to

which the shell is subjected, i.e., pressure × area, is then

$$dF = dP\frac{dV}{dR} = \frac{dP}{dR}\,dV, \tag{2.19}$$

where dP/dR is the pressure gradient in the given shell. As a reasonable approximation, it may be supposed that the pressure gradient is essentially constant across the core radius, so that

$$\frac{dP}{dR} \approx \frac{P}{R}, \tag{2.20}$$

where P is the total difference in pressure from the center of the core to the outer surface before expansion occurs. Hence, from equations (2.19) and (2.20),

$$dF \approx \frac{P}{R}\,dV. \tag{2.21}$$

2.50 The time required for the core to expand from radius R to $R(1+\delta)$, i.e., a distance of $R\delta$, is about 7 generations, as seen in § 2.38. However, as a rough approximation, this may be taken as $1/\alpha$, where α is the multiplication rate just prior to explosion time. The mean outward acceleration of the core material, and of the shell dV, may consequently be expressed as $R\delta\alpha^2$. The mass of the shell is ρdV, where ρ is the core density; hence, by Newton's second law of motion, i.e., force = mass × acceleration, the force dF acting on the shell is given by

$$dF \approx \rho dV \times R\delta\alpha^2.$$

Upon comparing this result with equation (2.21), it is seen that

$$P \approx \rho R^2\alpha^2\delta. \tag{2.22}$$

2.51 As in the calculation of the explosion time, the total energy of the core, assuming there is negligible loss during the initial expansion, is expressed by equation (2.17), namely,

$$E = \frac{PV}{\gamma - 1}, \tag{2.23}$$

where γ is the ratio of the specific heats of the gas. Using equation (2.22) for P and writing M/ρ for the volume of the core, M being the mass, equation (2.23) becomes

$$E \approx \frac{MR^2\alpha^2\delta}{\gamma - 1}. \tag{2.24}$$

2.52 If ϵ is the energy released in the complete fission of unit mass of core material, then the total energy available in the core is $M\epsilon$, and the efficiency, according to equation (2.18), is $E/M\epsilon$, where E is given by equation (2.24); consequently,

$$\phi = \frac{E}{M\epsilon} \approx \frac{R^2\alpha^2\delta}{(\gamma - 1)\epsilon}. \tag{2.25}$$

It should be pointed out that in the foregoing derivation no allowance has been made for depletion of the core material as fission proceeds. For low efficiencies, to which most of the other approximations made are applicable, the depletion is not significant and can be neglected. Moreover, no allowance has been made for the inertial effect of the tamper on the efficiency. For the present purpose, which is to obtain a qualitative guide to some of the factors determining the efficiency, this can also be ignored. Hence, replacing the quantity $1/(\gamma - 1)\epsilon$ by a constant, K, equation (2.25) can be written as

$$\phi \approx KR^2\alpha^2\delta, \tag{2.26}$$

which is a version of the Bethe–Feynman formula that was developed for slightly supercritical systems. The efficiency of a fission weapon is seen to depend on the factors R, α, and δ.

2.53 Since the efficiency of a fission weapon may be expected to increase as R^2 (at constant density), it would be advantageous for the core to be large at the time of the initiation of the fission chain. One way in which this can be achieved in practice, e.g., in a gun-type weapon, is to bring together subcritical masses which are designed to contain a large total mass of fissile material. Thus, for a given compression or, especially, for no compression, the efficiency would be expected to be greater the larger the mass of the assembled core.

2.54 In general, the most important factor in determining the efficiency of a fission weapon is α, and the latter increases in proportion to the compression (§ 2.19). The efficiency, according to equation (2.26), will thus be related, approximately at least, to η^2 (or to $\eta^{1.7}$ if the effect of tamper compression is included (§ 1.47)). In addition, although of lesser significance, the effect of compression on δ must be taken into account; the more highly compressed the core material

APPENDIX

A2.01 The average pressure P in a spherical imploding core of radius R is defined by

$$\bar{P}V = \bar{P}(\tfrac{4}{3}\pi R^3) = \int_0^R P\,(4\pi r^2)dr, \qquad (2.29)$$

where P is the pressure at the distance r from the center; hence,

$$\bar{P} = \frac{3}{R^3}\int_0^R Pr^2\,dr.$$

It follows, therefore, from equation (2.11), for a parabolic pressure distribution, that

$$\bar{P} = \frac{3P_0}{R^3}\int_0^R \left(1 - \frac{r^2}{R^2}\right) r^2\,dr. \qquad (2.30)$$

The integral in equation (2.30) may be evaluated as follows:

$$\int_0^R \left(1 - \frac{r^2}{R^2}\right) r^2\,dr = \int_0^R \left(r^2 - \frac{r^4}{R^2}\right) dr$$
$$= \frac{R^3}{3} - \frac{R^5}{5R^2} = \frac{2}{15}R^3.$$

If this result is inserted into equation (2.30), it is seen that

$$\bar{P} = \frac{2}{5}P_0. \qquad (2.31)$$

A2.02 Because of the pressure gradient in the core, the material will be accelerated, and this acceleration, $a(r)$, at the radial distance r, is given by the expression

$$a(r) = -\frac{1}{\rho}\frac{dP}{dr},$$

where ρ is the density of the core material. If P is again expressed by equation (2.11), then

$$a(r) = -\frac{P_0}{\rho}\frac{d\left(1 - \frac{r^2}{R^2}\right)}{dr} = \frac{P_0}{\rho}\frac{2r}{R^2}.$$

Hence, the acceleration, a, at the surface of the core, where $r = R$, is

$$a = \frac{2P_0}{\rho R},$$

so that

$$P_0 = \frac{\rho R a}{2}.$$

Upon inserting this expression into equation (2.31), it follows that

$$\bar{P} = \frac{1}{5}\rho R a,$$

which is equation (2.12).

UNCLASSIFIED

PREFACE

This report is one in a CNSS series that surveys the development of nuclear weapons over the past forty-five years. The unifying themes throughout the series are the technical advances and failures associated with new weapon systems, and the creation of the stockpile.

Authors, titles, and report numbers are listed below.

William G. Davey, *Free-Fall Nuclear Bombs in the U.S. Stockpile (U)*, LA-11397

William G. Davey, *Nuclear Tests Related to Stockpiled Weapons Development (U)*, LA-11402

Lawrence S. Germain, *A Brief History of the First Efforts of the Livermore Small-Weapons Program (U)*, LA-11404

Lawrence S. Germain, *The Evolution of U.S. Nuclear Weapons Design: Trinity to King (U)*, LA-11403

Lawrence S. Germain, *A Review of the Development of Los Alamos Gnats and Tsetses before the 1958 Test Moratorium (U)*, LA-11749

Raymond Pollock, *The Evolution of the Early Thermonuclear Stockpile (U)*, LA-11748

Raymond Pollock, *A Short History of the U.S. Nuclear Stockpile 1945–1985 (U)*, LA-11401

(All reports are classified Secret Restricted Data)

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A SHORT HISTORY OF THE U.S. NUCLEAR STOCKPILE: 1945–1985 (U)

Raymond Pollock

ABSTRACT (U)

This report, one in a series concerned with the history of nuclear-weapons research and development, examines the evolution of the U. S. nuclear weapons stockpile. The report distinguishes between weapon requirements resulting from strategic and operational demands and requirements created by technological advances. The acquisition of nuclear weapons through four distinct, evolutionary phases is also reviewed.

INTRODUCTION

The purpose of this report is to identify the possible causes of significant change in the U.S. nuclear-weapons stockpile as it evolved between 1945 and 1985. While we will be concerned with the relationship between stockpile characteristics and national security policy, we concentrate on qualitative changes rather than on inventories. Our principal interest is to distinguish between weapon requirements generated by strategic and operational demands and those resulting primarily from opportunities created by the advance of technology.

As a first step, we examine the diversity of the U.S. nuclear-weapons stockpile, or more particularly, its variation over time. Figure 1 shows the total number of distinct weapon systems (as distinguished by mark number), both strategic and tactical (non-strategic) weapons. The bar charts of Fig. 2 indicate, for the strategic category, system entries and retirements; the net of these determines the data points of Fig. 1. Figure 3 shows entries and retirements for non-strategic systems. Examination of these figures leads to the conclusion that between 1945 and 1985 the U.S. nuclear-weapons acquisition process proceeded in four distinct phases.

In the early postwar phase (1945–1950), the stockpile remained based on the wartime Fat Man and Little Boy designs. Air Force heavy bombers provided the only delivery vehicles, and the "atomic" bomb was clearly seen as solely a strategic weapon of awesome power.

During the second phase (1950–1955), the variety of stockpiled systems grew quite rapidly, as the results of postwar R&D allowed lighter, more efficient fission bombs to be developed. New, heavier bombers made possible the entry into stockpile of the first huge, high-yield, "emergency capability" thermonuclear weapons. And the first weapons developed especially for tactical applications made their appearance.

had been consolidated into the JSTPS, and the first SIOP was in effect. Nuclear support for the North Atlantic Treaty Organization (NATO) in the theater had been prepared and the weapons to implement NATO MC 14/2 were in procurement. The list of strategic weapons that entered stockpile during the last 5 years of the Eisenhower administration attests to the vigor of the nuclear production complex:

- B28 (thermonuclear bomb)
- B36 (thermonuclear bomb)
- B39 (thermonuclear bomb)
- B41 (thermonuclear bomb)
- W28 (thermonuclear warhead: Hound Dog, Mace)
- W39 (thermonuclear warhead: Bomarc)
- W47 (thermonuclear warhead: Polaris A1, A2)
- W49 (thermonuclear warhead: Thor, Jupiter, Atlas, Titan I).

The list of tactical weapons is equally impressive:

- W25 (fission weapon: Genie air-to-air defense missile)
- W27 (thermonuclear warhead: Regulus II)
- W30 (fission warhead: Navy Talos, TADM missiles)
- W31 (fission weapon: ADM,
- W33 (gun-assembled fission weapon: 8-in. artillery shell)
- W34 (multipurpose fission warhead: Hotpoint).

The momentum built up during the Eisenhower years carried over into the Kennedy Administration, even though Defense Secretary Robert McNamara found SIOP-62 too rigid and apparently lacking in strategic rationale. The new administration initiated a rethinking of strategy and doctrine and introduced flexible options into the SIOP, but did not slow the entry of new weapons into stockpile. As a result, by the end of 1965 the following additional nuclear systems had become operational:

Strategic:

- W38 (thermonuclear warhead: Atlas, Titan I)
- B43 (thermonuclear bomb)
- W53 (thermonuclear warhead: Titan II)
- W56 (thermonuclear warhead: Minuteman II)
- W58 (thermonuclear warhead: Polaris A3)
- W59 (thermonuclear warhead: Minuteman I).

Tactical:

- W44 (fission weapon: ASROC)
- W45 (fission weapon: MADM, Little John, Terrier, Bullpup)
- W48 (fission weapon: 155-mm artillery shell)
- W50 (thermonuclear warhead: Pershing I)
- W52 (thermonuclear warhead: Sergeant)
- W54 (fission weapon: Falcon, Davy Crockett, SADM)
- W55 (thermonuclear warhead: SUBROC)
- B57 (multipurpose fission bomb).

DOE (b)(3)

Except for the gun-assembled W33, which required extensive field assembly before firing, all stockpiled weapons were now sealed-pit designs. While there was much innovative detail, and a few really new wrinkles yet to be worked out, the major inventions had been made and heavily exploited, and the basic patterns of nuclear-weapons technology had been firmly established.

THE STOCKPILE FROM 1965

Since 1965, the growth in the nuclear-weapons stockpile has shown a character entirely different from that of the first two decades. Referring once again to Figs. 1 and 2, we see that only 23 new systems entered stockpile in the 20 years 1966–1985 and that 15 systems were retired during this period. The functional makeup of the stockpile, that is, the proportions dedicated to strategic and nonstrategic missions, remains steady at the pattern established by 1965. This pattern is consistent with a view that little change in fundamental U. S. nuclear strategy has taken place over the last 20 years. Apparently, no nuclear innovation during this period has been sufficiently dramatic to once more induce sea changes like those of the 1940s and 1950s. To a large extent, turnovers in the stockpile appear designed to make more effective use of the technologies first developed in the 1950s in order to match weapon systems to military requirements.

This is not to say that the art and science of nuclear weaponry has not advanced during the modern era. Steady progress in basic weapon technology and a few major technical innovations have substantially enhanced the operational and logistical utility of nuclear weapons. To examine this in detail, we shall in the balance of this report adopt an organization centered on distinguishing weapons by the operational requirements they are designed to fill. Specifically, we shall develop the history of the stockpile in seven different categories:

- Strategic offensive: land-based ballistic missiles
- Strategic offensive: sea-based ballistic missiles
- Gravity bombs
- Air-to-surface missiles
- Tactical missiles
- Defensive weapons
- Miscellaneous tactical weapons.

Before a chronological survey of stockpile development is resumed, the more important advances of the past 20 years will first be described.

Basic Knowledge

While not an identifiable single technology, increased knowledge of basic weapon physics, materials properties and behavior, electronics, and computing technology have resulted in substantial steady improvements in nuclear-weapons design and construction. Weapons designers have been able to use their understanding of the physics of weapon function, plus the marked improvement in their ability to model weapon behavior, to eliminate unnecessary weight and fit a given yield into a smaller envelope. At the same time, miniaturization of weapon electronics and the development of new structural materials have made it possible to use more of the total warhead volume for the nuclear physics package. The result has been a steady improvement over the years in the yield-to-weight ratio, reductions in warhead diameter and size, and the ability to tailor weapons to particular delivery modes.

Safety

It is noteworthy that, over the span of more than 40 years, there has never been an accidental detonation of a nuclear weapon that produced a nuclear yield. However, there have been accidents with nuclear weapons, and there have been accidental detonations of high explosive (HE) in nuclear weapons. Requirements for one-point safety adopted and enforced many years ago have ensured that, even in the event of an accident sufficiently severe to detonate the HE of a nuclear weapon, no significant nuclear yield will result. However, explosion and fire can still result in the dispersal of weapons materials—most notably plutonium—that still present a significant hazard to indigenous populations and cleanup personnel. The most noteworthy such event occurred in 1966 near Palomares, Spain, when a B-52 carrying four

While controversy over MX basing has clouded the program almost from its beginning—and is not yet completely settled—the process of choosing a warhead for MX was also not serene.

DOE (b)(3)

Segments of the Air Force strongly opposed this. however. arguing that Soviet construction of a new generation of "superhard" missile silos, control centers, and leadership bunkers made it imperative that the MX be used to improve U. S. hard-target kill capability. The March 1976 imposition of a 150-kt limit on nuclear test yields by the Limited Test Ban Treaty (LTBT) complicated the decision process. This meant that a new high-yield warhead for MX would have to be fielded without ever undergoing tests in its complete design configuration. Advocates of hard-target kill won the day fairly early on. but the specifics of the warhead remained uncertain for some time; for an extended period the W78 Mk-12A was carried as the baseline MX warhead. However, in early 1982 the Department of Defense (DoD) chose a new warhead, the W87, to be mated with the new Mk-21 reentry vehicle.

The W87 began the modern era of treaty-constrained development of high-yield warheads.

DOE (b)(3)

Sea-Based Strategic Ballistic Missiles

October 1965 saw the last ballistic-missile nuclear submarine (SSBN) patrol of the Polaris A1 missile and the start of development of the Poseidon C3 missile for the new Poseidon boats. Only 5 years after the first Polaris SSBN had gone on station, the Navy was retiring the earliest elements of its first-generation SLBM force and was entering development of a second, MIRVed generation.

DOE (b)(3)

Neither of the Polaris versions offered very good delivery accuracy, nor would this be a requirement on the yet-to-be-developed Poseidon C3. The primary mission of the SLBM force seemed to be to provide a secure retaliatory force, either to meet the requirements for finite deterrence, spelled out 10 years earlier by Arleigh Burke, or to pave the way for SAC bombers by knocking out defenses, as stipulated by President Eisenhower. In any case, the SLBM force was clearly designed for soft targets.

DOE (b)(3)

The Trident program began as ULMS—Undersea Long-Range Missile System—in 1969 as a result of the STRAT-X studies. As a follow-on to Polaris/Poseidon, Trident was envisioned as a quieter submarine, carrying missiles that could be launched at intercontinental range. The need for Tri-

dent was driven by two primary considerations: a replacement for Poseidon would be needed before the end of its projected service life of 20 to 25 years, and the replacement submarines should operate over a wider range of ocean in order to ensure survivability against a growing Soviet surveillance and ASW capability. Development of the Trident I C4 missile and the Ohio-class Trident boat was approved by the Secretary of Defense in September 1971.

The Trident I missile was sized to allow retrofit into the smaller Poseidon SSBNs—a later Trident II missile will fit only the larger Trident boats. By the time the W76 warhead for the C4 was selected in 1973, the Navy had become more interested in missile range than in any further fractionation of payloads.

DOE b(3)

DOE (b)(3)

[redacted]

liver its full load of eight W76 warheads to ranges greater than those attainable by an off-loaded Poseidon C3. Although the accuracy of the [redacted]

DOD 1.5(c) (x)

The W76 is the latest SLBM warhead to enter stockpile. [redacted]

DOE (b)(3)

complete the Navy's conversion from concentration solely on soft targets.

DOE (b)(3)

[redacted]

Gravity Bombs

The story of gravity bombs since 1965 is to a large extent the story of the B61 bomb in all its variants. The B61, which entered Phase 3 development in January 1963, is a multipurpose modern tactical bomb, weighing approximately 700 lb, which now exists in eight models designed for air delivery by both strategic and tactical forces. Because the B61 is a truly multipurpose weapon, carried by a wide variety of U. S. and Allied aircraft dispersed all over the world, the development and refinement of B61 mods has been heavily influenced by requirements for safety and security. All B61 variants but one carry Permissive Action Link (PAL) arming systems, and some of the earlier mods that predated the introduction of IHE are now being replaced by versions employing an IHE primary and more elaborate safety and security systems.

DOE (b)(3)

[redacted] The Mod 0 employs a Category B PAL, requiring entry of a four-digit code to arm the weapon. The Mod 1 does not have the PAL (it is intended for Navy use); otherwise, it is identical to the Mod 0. Both of these early versions use PBX9404 HE. [redacted]

DOE (b)(3)

his version also incorporates command disable, which will destroy critical components of the warhead on coded command. The B61 Mod 5 is the last of the non-IHE versions.

DOE (b)(3)

[redacted]

Beginning with the Mod 3, IHE has become standard equipment for B61s, along with weak link/strong link and unique sig-

in the strategic stockpile. Simultaneously, the intensified Soviet threat to Europe and the consolidation of U. S. nuclear strategy led to the introduction of large numbers of weapons designed for tactical/theater applications. During this period, the three legs of the strategic triad were established and the first SIOP was developed. While progress in nuclear-weapon technology continued to play a major role, technical advance across a broader front, including electronics and ballistic-missile technology, became very important. This era, perhaps more than any other, displays the symbiosis of nuclear and nonnuclear technologies in both prodding and responding to military requirements.

The fourth phase, extending from about 1965 to 1985, might be characterized as largely a period of refinement. While the total number of stockpiled weapons has varied over these years, the number of distinct types—mark numbers—has stayed relatively constant until the recent Reagan administration buildup. Second- or even third-generation warheads have replaced earlier systems, offering quantitative improvements in performance and operational characteristics. Technical advance in the state of the art in nuclear weaponry has continued, but military requirements have become the dominant force in determining the shape of the stockpile.

REFERENCES

1. David Alan Rosenberg, "The Origins of Overkill—Nuclear Weapons and American Strategy, 1945–1960," International Security VII, No. 4 (Spring 1983), pp. 15–16.
2. Ibid., p. 16.
3. Ibid., p. 61.
4. Ibid.
5. Ibid., pp. 62–63.
6. Ibid., pp. 4–5.
7. Ibid., pp. 65–66.
8. Ibid., p. 66.

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The Future of Non-Strategic Nuclear Forces

Are These Capabilities Still Needed? (U)

Joseph S. Howard II
Edward I. Whitted

April 30, 1991

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SECRET

EXECUTIVE SUMMARY

Background

The world has witnessed such revolutionary changes over the past 18 months that clearly a new era has started. In this context, the authors undertook a study in late 1989 with partial Army support that would assess future European short-range nuclear force (SNF) structures and target sets. The rapidity of the political changes in Europe and the Soviet Union at the early stages of the effort motivated broadening the study to include strike non-strategic nuclear forces (NSNF) in a worldwide context. Also, the nature of the evolving era indicated that a traditional target-based analysis would be sadly deficient without underlying policy and economic assessments. These assessments have led us to conclude that, even more than before, future stockpiles will not be determined strictly on the basis of threat target defeat. Stockpiles will be configured from a complex interaction of domestic and international politics, defense budgets, arms control treaties, and differing threat perceptions.

The events in Europe are also affecting US NSNF strategies for other theaters. The outcome of future Nuclear Weapons Requirements Studies (NWRS) from the nuclear CINCs may profoundly affect NSNF roles and missions of the services. Trends in late 1990 were moving toward a denuclearization of the Army in the sense that organic nuclear systems might be retired.

Therefore, this paper examines the 1995-2000 rationale, roles, and capabilities of US NSNF in light of the revolutionary changes in Europe, plausible future nuclear threats worldwide, and downward trends in NSNF due to economic and political pressures.

Policy Findings: Strong Reasons for NSNF

The strategy and policy reassessment of US NSNF identified strong rationale for a continued role:

- As a visible instrument of superpower status in an uncertain and unpredictable world

- As a deterrent to future non-superpower nuclear-capable adversaries in a proliferated world

- As a deterrent to regional Soviet or Russian aggression as long as resurgence or reconstitution remains feasible

- To provide stability and insurance in a post-CFE Europe through a small air-delivered, forward-deployed force

Because of European politics, US NSNF structure decisions must be broader than peacetime NATO strategies, policies, and constraints.

I. INTRODUCTION

- **Purpose**
- **Scope**
- **Objectives**

Non-strategic nuclear forces (NSNF) have composed a significant portion of the US nuclear stockpile due, primarily, to their deterrent capabilities against the Soviet Union and its conventional and theater forces. But the political watersheds of 1989 and 1990 in Europe are causing, and rightfully so, NATO governments, policymakers, and the public to challenge the need, roles, and composition of US forward-based nuclear systems.

The events in Europe are also affecting US NSNF strategies for other theaters. The outcome of future Nuclear Weapons Requirements Studies (NWRS) from the nuclear CINCs may profoundly affect NSNF roles and missions of the services. Current trends are moving in the direction of a denuclearization of the Army in the sense that organic nuclear systems might be retired

This paper examines the future rationale, roles, and capabilities of US NSNF in light of the revolutionary changes in Europe, plausible future nuclear threats worldwide, and downward trends in NSNF from economic and political pressures.

We conclude that NSNF still have a critical role to play within future US defense strategy. Our findings (summarized on pages 62–63) include the need for a flexible and versatile force through a variety of systems, including an organic Army capability and an Air Force theater stand-off capability, but at substantially reduced numbers from the present. The rationale for US NSNF should broaden its focus from Europe, where a small force of air-delivered munitions may remain for stability and insurance, to one embracing roles both as a deterrent against future regional adversaries with incipient nuclear capabilities, and also as a US political instrument of power in a multipolar world.

The old *raison d'etre* for US NSNF: the Soviet Threat

1. **Democracies and economies of Western Europe**
2. **The overriding threat: the Soviet Union**
3. **NATO was unable to provide sufficient conventional forces**
4. **Deployment of nuclear weapons to Europe created an extended deterrence umbrella for conventional force deficiencies**

Other US CINCs were also allocated NSNF for deterrence of the worldwide Soviet Threat

Initially behind the deployment of US forward-based nuclear forces has been the threat of Soviet landpower, and subsequently the Soviets' own theater nuclear capabilities. The victory of the allies in the Second World War led to several unforeseen events: one was the raising of the Iron Curtain in the late 1940s through the subjection of Eastern European countries by the Soviet Union. The US, after fighting a war against totalitarianism, turned to a grand strategy of containment of Soviet imperialism. A free and prosperous Western Europe continued to be of utmost interest to the US; and therefore, the NATO alliance was formed to draw the line against further Soviet expansion. Unfortunately, the Soviet Union and its Warsaw Treaty Organization (WTO) alliance deployed forces far beyond those required for its own defense. Unable and unwilling to match the conventional force goals of the 1952 Lisbon Conference, the US deployed its first theater nuclear weapons for NATO in 1953.

Over the past 45 years, NATO nuclear doctrine has evolved from "massive retaliation" in MC 14/2, to "flexible response" in MC 14/3, then to the development of provisional political guidance (PPG) for initial and follow-on nuclear use, next to the Montebello modernization decisions, and now to the proposed "weapons of last resort" from last summer's London communique. But behind all of these declaratory doctrines and revisions, excepting the last, has been the massive Soviet threat.

The US strategy of extended deterrence, operative with the forward-deployment of US weapons and nuclear guarantees to the allies, has created a tension between the Europeans and the US. The presence of US weapons in Europe has been emphasized by the Europeans as a coupling to the US Central Strategic Forces. Hence, the specter of Armageddon must always reside in the calculus of the Soviet Union. Conversely to the US, the presence of theater nuclear weapons (now NSNF) gave an aura of credible response options before the ultimate response.

Several important factors drove stockpiles to large sizes

- **The size of the Soviet threat continued to grow**
- **The advances in nuclear weapon and delivery system technologies allowed for a myriad of theater/tactical delivery systems**
- **All three services deployed systems, developed operational concepts, and trained personnel to provide a variety of NSNF capabilities**
- **The political element of Allied participation for credible NSNF deterrence led to NATO programs of cooperation**

One byproduct of the end of the Cold War will be a large builddown of NSNF warheads. This warhead reduction will be in the thousands, a legacy of the Cold War balancing between the US and the Soviet Union.

The two major powers have competed with such vigor that arsenals grew to thousands of theater nuclear weapons on both sides. The US and the NATO alliance perceived that the massive Soviet land and theater nuclear capabilities presented an unacceptable threat to Western Europe without the political and military power of large nuclear weapon inventories. Further, this Soviet threat grew and modernized without abatement until the economic realities of a nearly bankrupt economy began to become so apparent in the last two years. But even today the bureaucratic resistance and inertia to change exists: 'Comrades, we have converted our factories to produce washing machines and sewing machines....but half of the time a tank still rolls out.'

Another reason for the large stockpiles stemmed from the remarkable technological advances in the period of the 1950s to 1970s. Warhead and carrier developments allowed a myriad of systems to be developed and deployed. The apex of the Cold War fostered budgets and political support for nuclear weapons that might never be seen again.

All three services also justified the need for their own NSNF. For example, the Army spent considerable resources in the 1950s toward the development of the nuclear battlefield with the Pentomic Division, which involved an extensive process of developing and testing ground forces in simultaneous operations with conventional and nuclear fires. The other two services also devoted significant resources to their nuclear programs.

In NATO, programs of cooperation were instituted for allied participation in the US extended deterrence strategy, thereby increasing stockpiles.

NATO is entering a new epoch: its strategy is evolving

- **The London Communique is a harbinger**
  - Proposal to WTO: Non-aggression treaty, no longer adversaries
  - Nuclear forces are weapons of last resort
  - Elimination of nuclear artillery shells
  - Significantly reduced role for sub-strategic weapons of shortest range

- **The Soviet Union is no longer perceived to be a credible threat to Western Europe**
  - No intentions to attack
  - Capabilities to conduct a theater strategic offensive no longer credible
  - Must mobilize and pass through neutral or unfriendly East European nation(s)

- **The economic and political imperatives are reducing NATO & Soviet forces**
  - Declining budgets for forward-deployed conventional and NSNF forces
  - CFE treaty reducing conventional armaments
  - Short-range nuclear force agreements

The revolutionary changes of the past two years demand that NATO adapt its nuclear weapon strategies in order to preserve political legitimacy and acceptability. The first official response to the new era is the London Declaration of July 1990. By recognizing the disappearance of the Soviet short-warning and large-scale theater strategic operations (TSO) threat, the communique discounts the need for short-range nuclear forces, and offers the elimination of nuclear artillery shells. Furthermore, the joint declaration stipulates that NATO nuclear weapon strategy is moving away from "flexible response" to "weapons of last resort." As part of this revision, the President terminated the Follow-on-to-Lance modernization program. Clearly, the debate is just starting and will be controversial as to the future shape of NATO nuclear policies and stockpiles.

Indeed, many NATO thinkers and policy makers maintain that the Soviet Union should no longer be considered an adversary since their aggressive intentions are gone. They argue that the collapse of the WTO and the planned withdrawal of Soviet forces from Eastern Europe by 1994-95 reduces their capabilities to, at best, limited aggression. Only the threat remains of a reconstituted and resurgent Soviet Union after lengthy mobilization, however remote. And the probability of that event is considered to be so small by many in NATO governments as to be no longer a politically legitimate scenario for the maintenance of large NSNF stockpiles in Europe.

The ongoing economic crises in the Soviet Union are to a lesser degree matched by the deficit problems of the US budget and the calls for a peace dividend. Other NATO nations are already planning for large defense reductions. Eventually the CFE treaty may act more as a floor to defense cuts rather than a ceiling. SNF understandings and agreements will be in the forefront of arms control negotiations pending completion of the CFE treaty.

But Future Regional Threats dictate three NSNF Deterrent Rationales broader than European stability forces

War prevention and war termination where US vital interests are involved:

2. A visible symbol of national power in an uncertain & unpredictable multipolar world

3. A deterrent to future non-superpower nuclear–capable adversaries in a proliferated world

4. A deterrent to regional Soviet or Russian aggression as long as resurgence or reconstitution remains feasible.

NSNF Roles

- **An incalculable risk to the threat(s)**
- **Appropriate & credible non-strategic nuclear options including capabilities for in-kind nuclear response**
- **Direct defense of endangered US forces**

The first major rationale for NSNF derives from its contribution as a political instrument and an insurance policy for the superpower US Although not often on center stage in a number of regional disputes or conflicts, NSNF availability in the wings has certainly played an important role in diplomatic interchanges and crises.

A future nuclear-proliferated world would present enormous challenges to US defense interests. Over ten nations possess the capabilities to obtain nuclear armaments in the next decade. Several of these nations maintain profoundly hostile relations to the US As regional powers in their own right with significant conventional armaments, their addition of nuclear capability would raise grave risks to deployed US forces.

While the aggressive intentions of the Soviet Union towards Europe may have disappeared, their conventional and nuclear capabilities remain huge. While the short-warning scenarios are no longer credible, a future resurgent and mobilized Soviet Union remains feasible. While intentions can move towards amicability, they can subsequently be reversed upon change in leadership. The Soviet Union or the greater Russian Republic, should some republics become autonomous, may have future cause to counter US vital interests in critical regions such as Southwest Asia, despite present trusts.

Therefore, we are incredulous of US forces without NSNF to prevent war or to terminate war against hostile nuclear-armed states. The rationale for NSNF must rest upon its capabilities to deter a plausible resurgent Soviet Union, or any of several regional powers with potential nuclear capabilities. As NSNF kept the long peace in Europe because it engendered cautious behavior, so should NSNF be kept as an incalculable risk towards any nuclear state contemplating aggression.

The rationale for NSNF also involves the element of credibility: the NCA should have options other than central strategic forces for an appropriate response.

Credible deterrence

necessitates *will* to employ nuclear weapons as

expressed in declaratory strategies and roles,

and effective military *capability*

Capability is assessed in this study by analyzing the effectiveness of arms control-restricted, policy-driven, and budgetary-constrained stockpiles against reduced target sets

An axiom – the degree of nuclear deterrence relates directly to will and to capability. Declaratory strategies and roles ought to express national will in explicit terms that will deter potential adversaries. Capability ought to be visible, perceived as effective, and trained with in peacetime to ensure that no doubts are raised concerning its credibility during crises or armed conflicts.

For the post-Cold War era, the target sets reflect substantial reductions in type and numbers. The availability of two systems, the Air Force SRAM T and the Army W79 for the 8-in. howitzer, is questionable in light of ongoing arms control, policy, and budgetary debates. The capabilities analyses that follow incorporate these considerations.

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June 6, 1995

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Survey of Weapon Development and Technology (WR708) (U)

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Classified by: S. J. Barnes Dept. 3522
Title : Manager Date: June 6, 1995

CRITICAL NUCLEAR WEAPON DESIGN INFORMATION
-- DOD DIRECTIVE 5210.2 APPLIES --

~~NUCLEAR WEAPON DATA~~

~~SIGMA 1 & 2~~

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW	
1ST REVIEW-DATE: 5/23/96	DETERMINATION [CIRCLE NUMBER(S)]
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USAF brackets green
Army agree
Navy agree

Corporate Training & Development 3522

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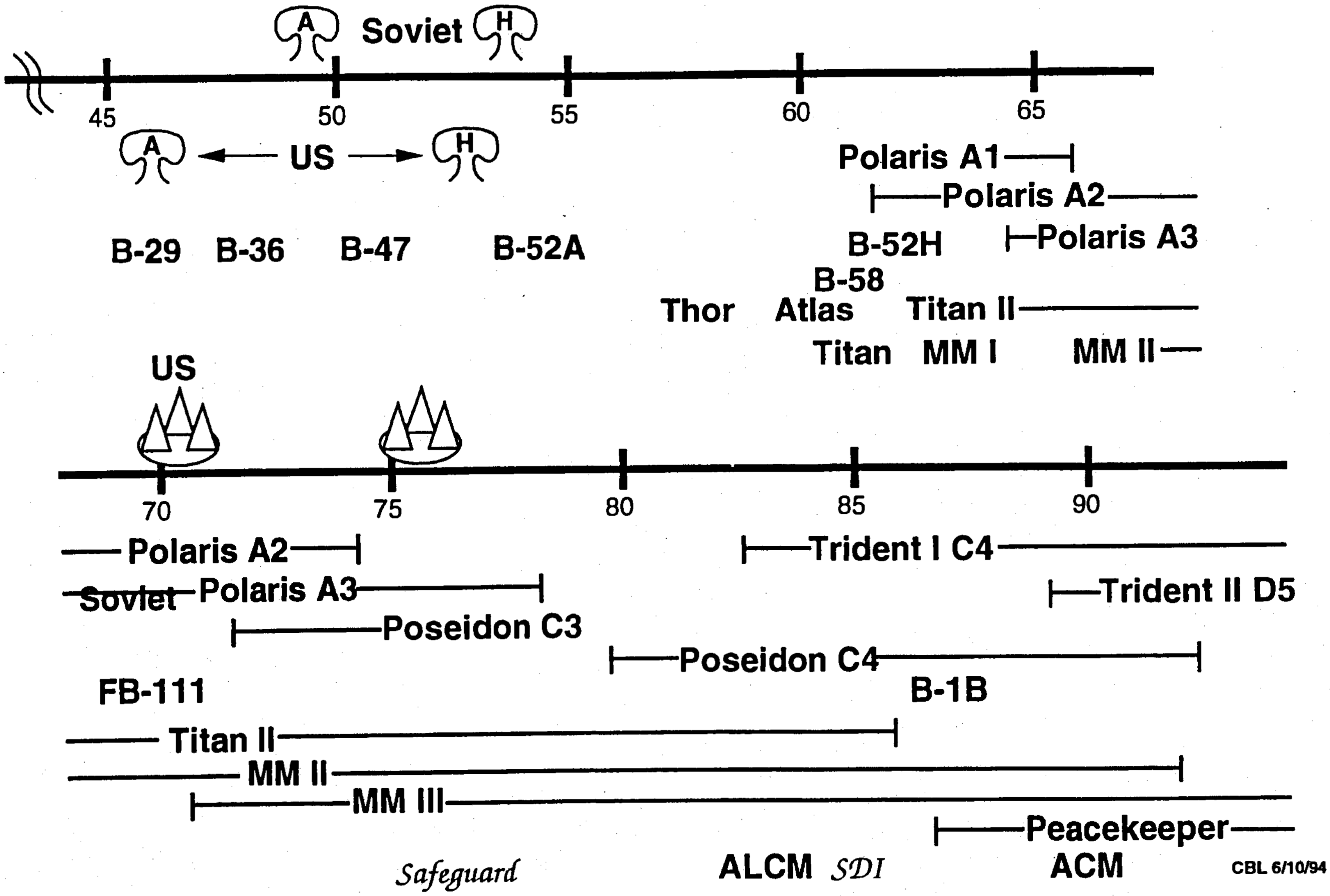
Strategic Delivery Systems



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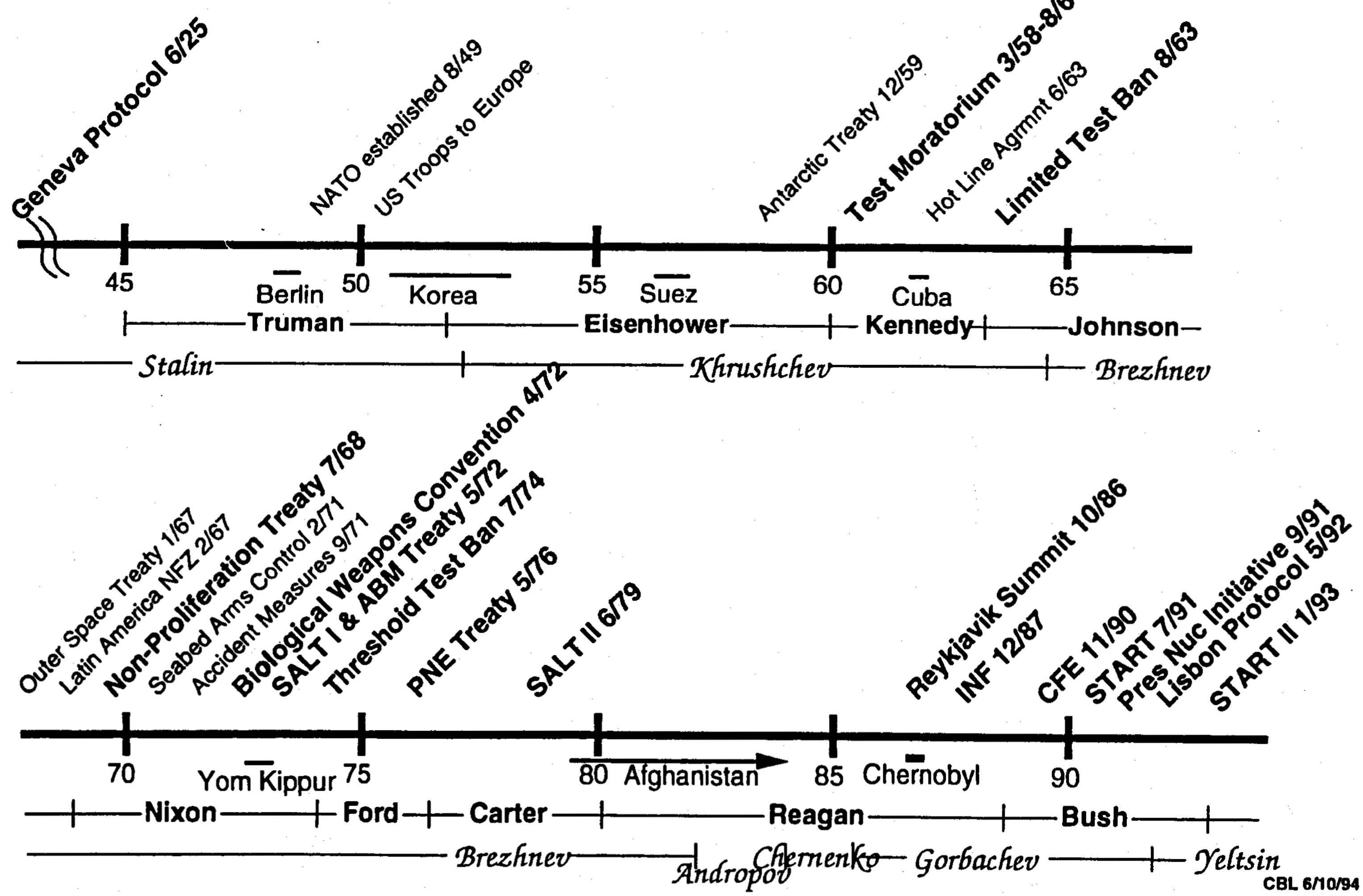
Arms Control Treaties



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SALT I - 1972

Interim Agreement on Strategic Offensive Arms

Limited launchers (silos and sub tubes) to the then current number

US - 1710 SU - 2347

Limit on heavy launchers (SS-9 and later SS-18)

Five year duration

US ratified in Oct 1972

Reagan repudiated SALT I and II in May 1986

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ABM Treaty - 1972

Johnson and McNamara tried to convince Kosygin at Glassboro to limit ABM systems - June 1967

US announced Sentinel program in September1967

ABM talks were postponed by Soviet invasion of Czechoslovakia in 1968

Nixon changed concept to Safeguard, protecting ICBMs and Washington, DC

Treaty prevents defense of territory, limits to 2 sites with 100 interceptors, limits LPARS

Forbids mobile ABMS or sea, air, or space systems

OPP, Krasnoyarsk, SCC, capabilities questions

[redacted] UNCLASSIFIED

START Treaty - 1991

Signed July 31, 1991, 5 months before the end of SU

Lisbon Protocol, signed May 1992, committed Russia, Ukraine, Belarus, and Kazakhstan to START (and NPT)

START limits SNDVs and deployed warheads:

	START	US forces*	Soviet forces*
SNDVs	1600	2246	2500
ICBM & SLBM Warheads	4900	8210	9416
Total Warheads	6000	10563	10271
Heavy ICBM Warheads	1540	------	3080
Mobile ICBM Warheads	1100	------	618
Throw-wt ICs & SLs (metric tons)	3600	2631	6626

*as of 9/90

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[redacted] UNCLASSIFIED

START II - 1993

Treaty between the Russian Federation and US, signed by Bush and Yeltsin January 3, 1993, codifed agreements of the Washington summit of June 17, 1992.

START II builds on START - and requires START

	START	START II Ph1	START II Ph2
Start Warheads	6000	3800-4250	3000-3500
ICBM & SLBM Warheads	4900	no sublimit	no sublimit
MIRVed ICBM Warheads	N/A	1200	0
SLBM Warheads	N/A	2160	1700-1750
Heavy ICBM Warheads	1540	650	0
Mobile ICBM Warheads	1100	1100	1100

Phase one to be complete 7 years after entry-into-force, Phase two by 2003

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ARMS CONTROL IN THE ANCIENT WORLD

1269 BC	**Earliest known peace treaty (Egypt and the Hittites), cemented by the marriage of Ramses II to a Hittite princess.**
1100 BC	**Philistines restrict the use of iron by the Israelites (1 Samuel 13:19-20).**
700-800 BC	**"...and they shall beat their swords into plowshares..neither shall they make war anymore" (Isaiah 2:2-4).**
546 BC	**Following the first recorded arms control conference, a "cessation of armaments" ends 72 years of hostilities in the Yangtse River Valley in Honan Province, China.**

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ARMS CONTROL IN THE ANCIENT WORLD (CONT'D)

400-500 BC	Athens and Sparta agree to dismantle fortifications although during the negotiations the Athenians hedged their bet by continuing to build their ramparts "high enough to be defended" (Peloponnesian War, Thucydides). Note that, according to the Aristophanes, the women of Athens and Sparta, under the leadership of Lysistrata, tried a different approach to forcing an end to hostilities!
450 BC	Socrates to Glaucon -- no use of poisoned weapons or poisoned water (The Republic, Plato).
300-400 BC	No weapons concealed in wood, no barbed or poisoned points, no points "blazing with fire" (India's Book of Man).
202 BC	After the battle of Zama, Carthage is required to surrender all war elephants and all but 10 triremes to Rome (Book XXX, Livy).

The Changing Context

Old	New
Bipolar Rigidity	Multipolar Complexity
Predictable	Uncertain
Communism	Nationalism/Religious Extremists
U.S. Dominant Western Power	U.S. Militarily No.1 - Not Economical
Fixed Alliances	Ad Hoc Coalitions
"Good Guys and Bad Guys"	"Grey Guys"
U.N. Paralyzed	U.N. Viable

Ref.: National Security in the 1990s: Defining a New Basis for U.S. Military Forces, Rep. Les Aspin, Chrmn House Armed Services Committee, January 6, 1992

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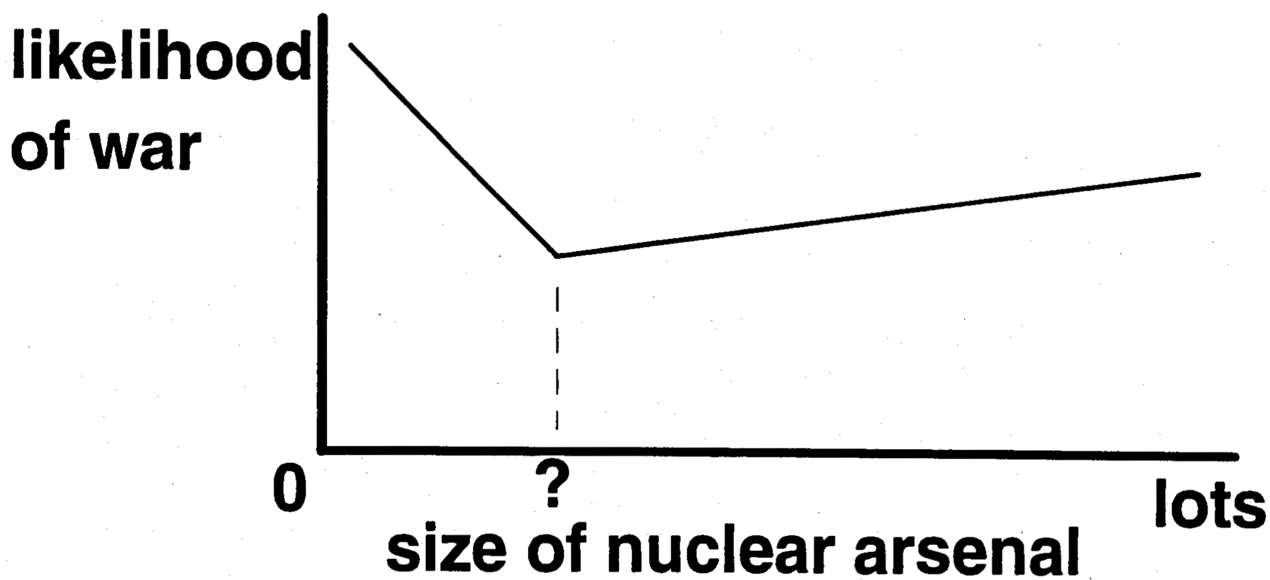
Nonproliferation Initiative

Why Not Zero?

Many nations and individuals want us to completely eliminate weapons -- attractive philosophy but dubious policy:



There may be things worse than nuclear weapons (e.g. biologics)

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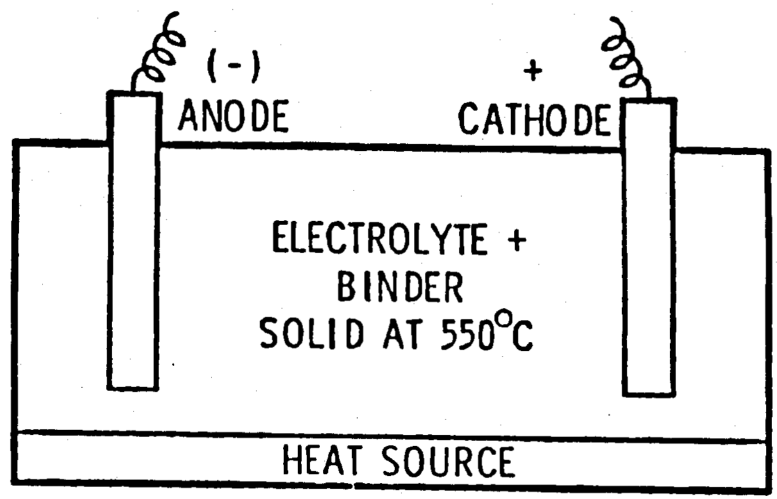
Nuclear Weapon Batteries

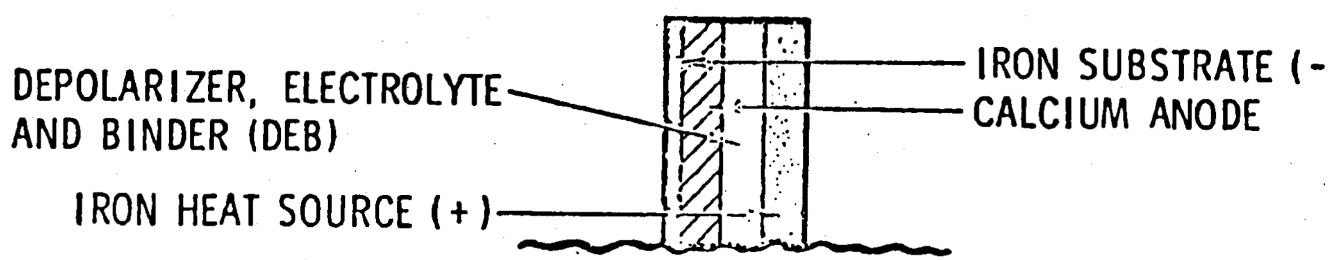
Little Boy	NT—6	Lead Acid	1945
Fat Man	ER—12	Lead Acid	
MK 4, 5, 6, 7	MC193	Nickel—Cadmium	1953
MK 12	MC271	Silver—Zinc	
MK 15	MC473	Thermal Ca—$CaCrO_4$	1955
Multiple	Multiple	Thermal Li—FeS_2	1970's
All New Designs		Thermal Li—FeS_2	Present

NOTE: JTA's, controllers, and support equipment may utilize designs other than thermal batteries

NEW PELLETIZED CELL



ANODE	- CALCIUM ON IRON SUBSTRATE	
CATHODE	- CALCIUM CHROMATE (depolarizer)	DEB
ELECTROLYTE	- LITHIUM CHLORIDE, POTASSIUM CHLORIDE + SiO_2 BINDER	DEB
HEAT SOURCE	- IRON-POTASSIUM PERCHLORATE DISC	
CELL CASE	- NONE	



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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

Day	Time	Session	Title	Instructor
Monday	8:30 - 12:00	1	Course Overview - Introduction	Hogan/Layne
		2	Physics - Explosion Theory	Hogan/Layne
	1:00 - 4:00	2	Physics - Explosion Theory (cont)	Hogan/Layne
		3	Nuclear Effects	Hogan/Layne
Tuesday	8:00 - 12:00	4	High Explosives - Detonators	Hogan/Layne
		5	Fission	Hogan/Layne
	1:00 - 4:00	5	Fisson (cont)	Hogan/Layne
		6	Thermonuclear	Hogan/Layne
Wednesday	8:00 - 12:00	6	Thermonuclear (cont)	Hogan/Layne
		7	Safety	Hogan/Layne
	1:00 - 3:00	7	Safety (cont)	Hogan/Layne
		8	Use Control - Access Control	Hogan/Layne
	3:00 - 4:00	9	Weapons Systems	Rogulich
Thursday	8:00 - 12:00	10	Dismantlement	Longmire
		11	Arming, Firing, and Initiation	Longmire
		12	Nuclear Testing	Hogan/Layne
	1:00 - 4:00	13	Transfer Systems	Robinson
		14	Fuzing	Hartwig
		15	Arms Control	Hogan/Layne
Friday	8:00 - 9:30	15	Arms Control (cont)	Hogan/Layne
	9:45 - 10:45	16	Non-Proliferation/Counter Proliferation	Taylor
	11:00 - 12:30	17	Stockpile Matters	Hogan/Layne
	1:30 - 4:30	18	Nuclear Weapons Musuem Tour	Hogan/Layne

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National Security Strategy: Deterrence

Decade	Implementation
1950	Massive Retaliation
1960	Flexible Response
1970	Flexible Response
1980	Flexible Response
1990	Last Resort

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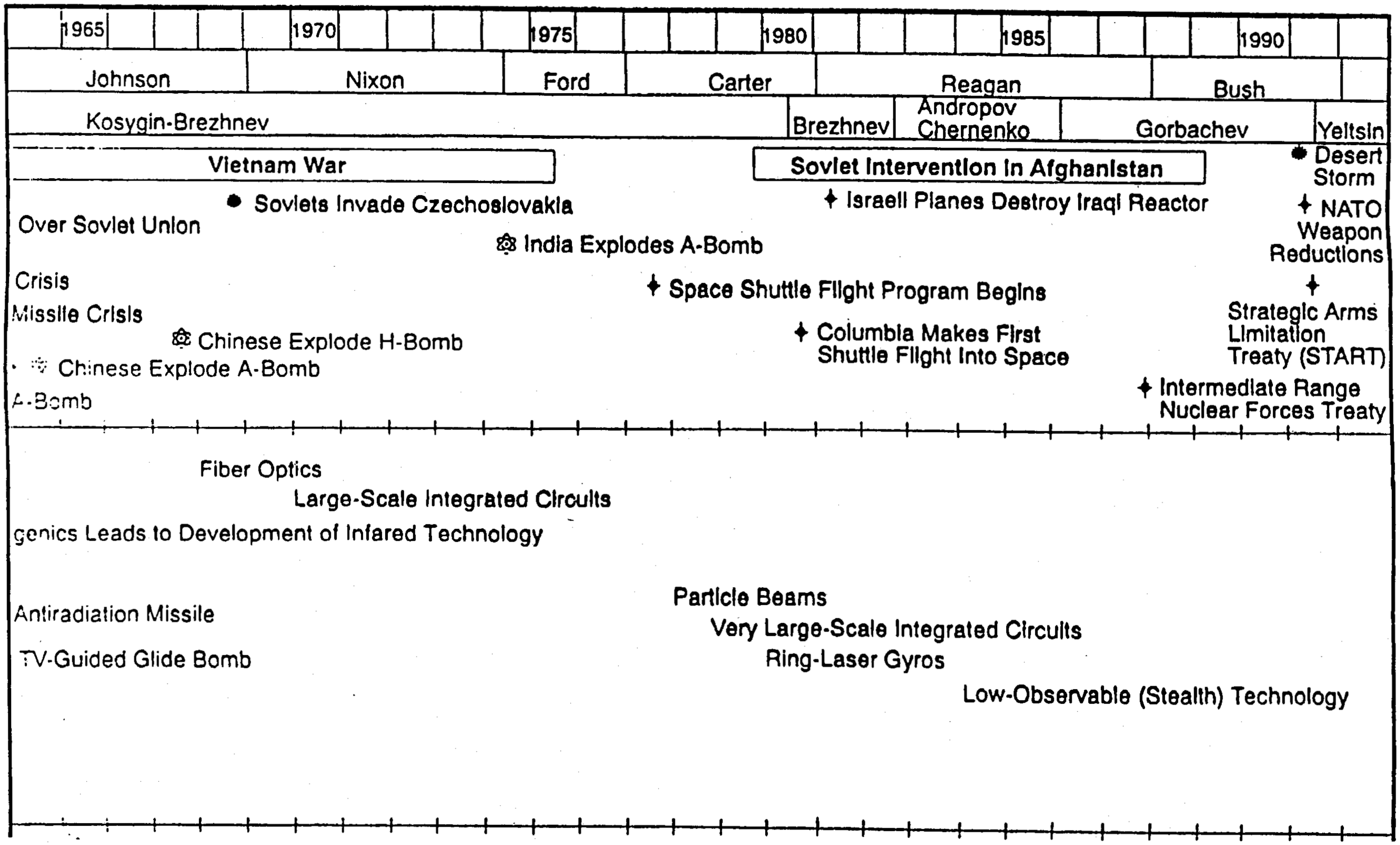
SIGNIFICANT HISTORICAL EVENTS RELATIVE TO NUCLEAR WEAPONS



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Strategy, Arms Control, and Weapon Systems Technology Drive Stockpile Requirements

Strategy	Threat	Tech.	Size/Wt.	Yield	Arms Control	Number
1950 Massive retaliation	Global	A/C & missiles inaccurate	Large	Very high	Very limited talks	Growing
1960 Flexible response	Global Theater	A/C & missiles improve	Decrease	Decrease	Limited talks	Growing
1970 Flexible response	Global Theater	A/C & missiles improve accuracy	Decrease even more	Tactical needed lower yields	SALT ABM limitations	Decline
1980 Flexible response	Global Theater	A/C & missiles very accurate	Large decrease	Continued decrease	Mutual elimination & reduce	Decline more
1990 Last resort	Theater Global	A/C & missiles very accurate	Remain small	Remain same	Large cuts mutual elimination/ unilateral	Large reduction

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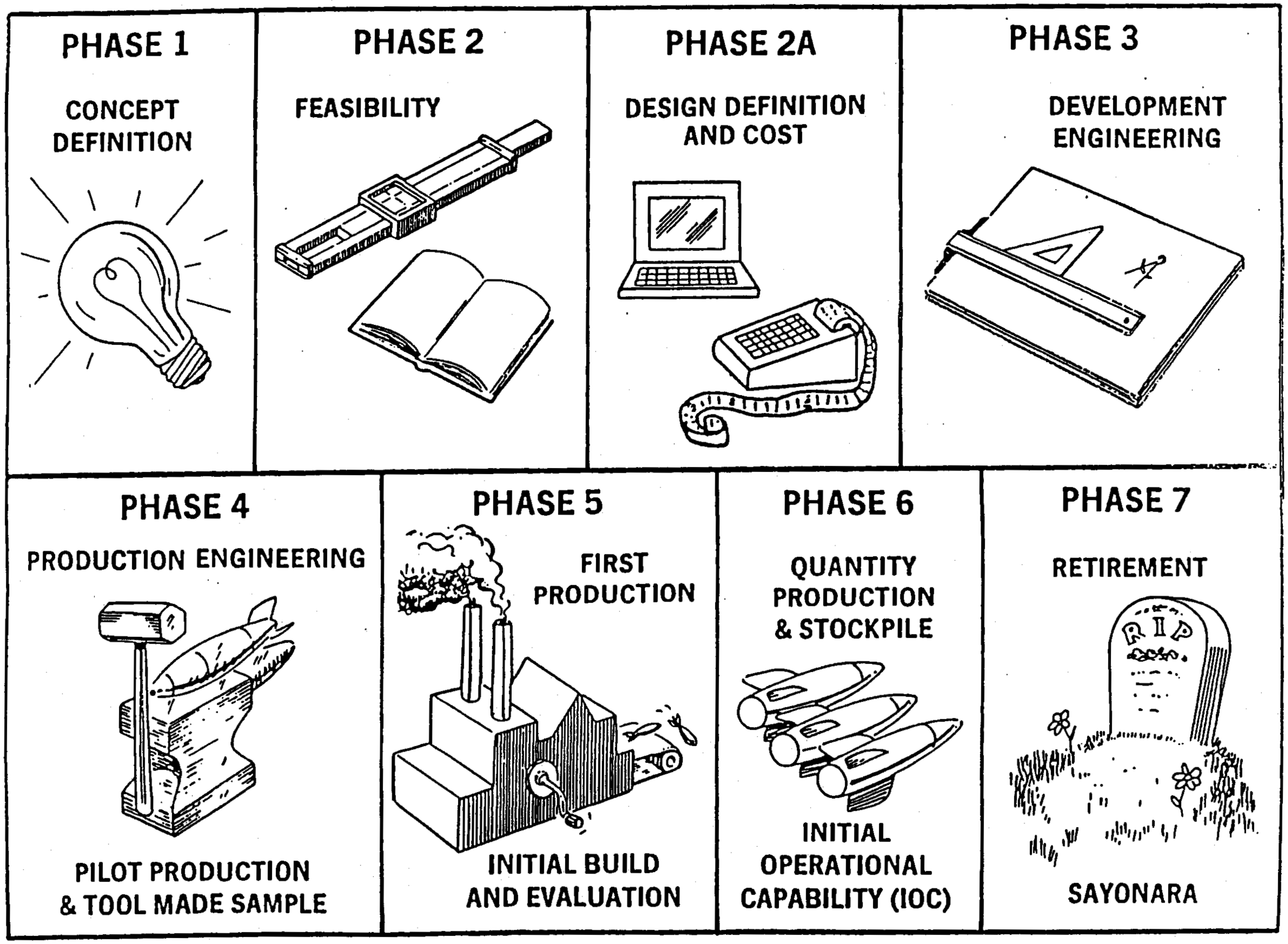
WEAPON DEVELOPMENT



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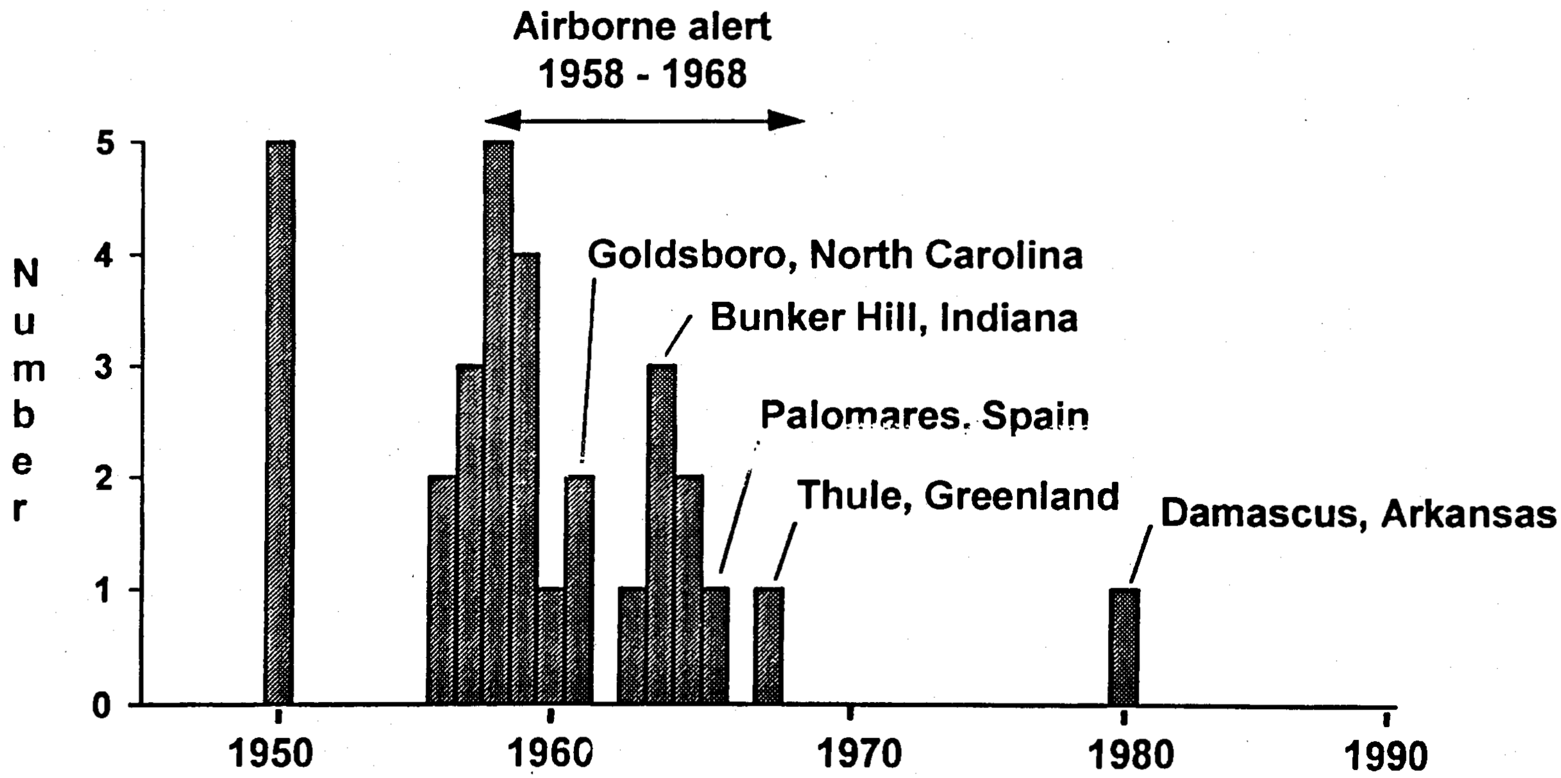
US Nuclear Weapon Accidents



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DISABLEMENT

- When initiated, disables certain key nuclear detonation-essential components.

- Non-violent outside the weapon case.

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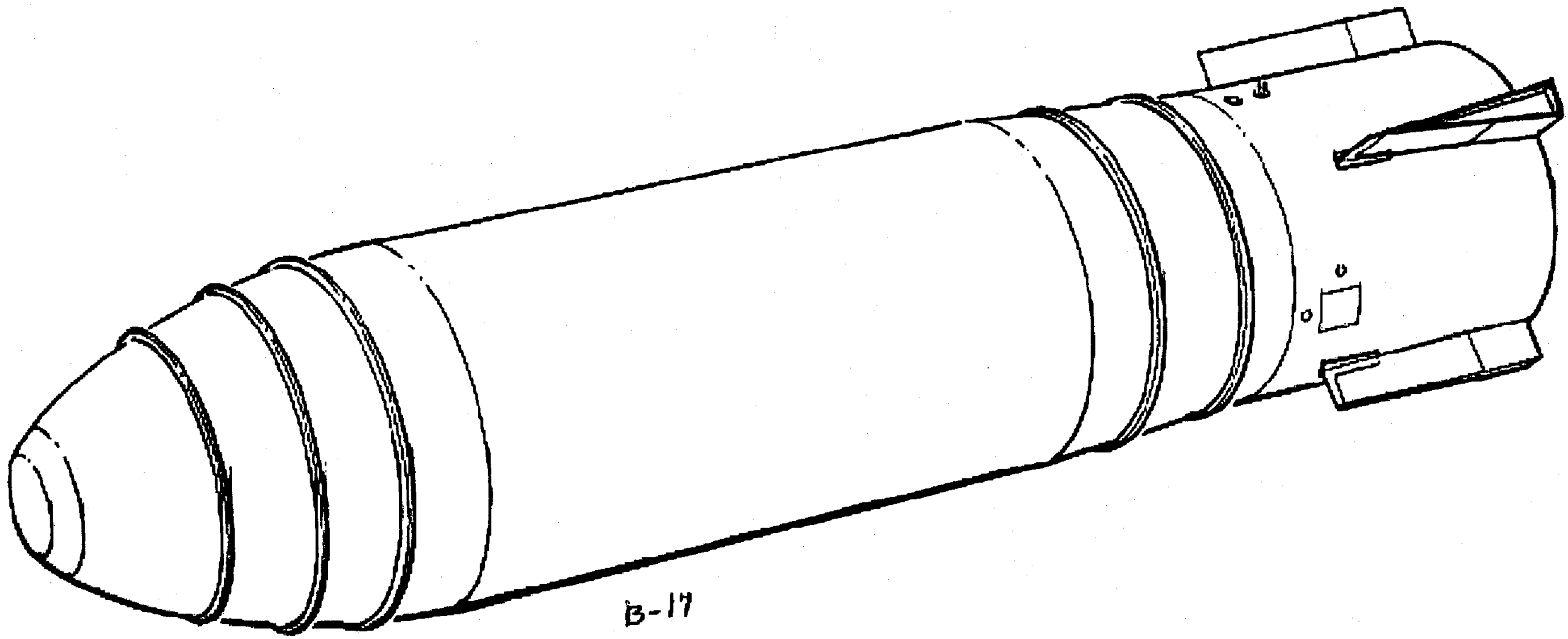

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B17 Bomb

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THIS [redacted] NO. [redacted] LANL-A.

October 13, 1949

TO: Technical Council Members

FROM: Edward Teller [redacted]

SUBJECT: THE SUPER BOMB AND THE LABORATORY PROGRAM

ADWD-2-7 [redacted]

~~CAUTION~~

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On Monday there will be a discussion in the Tech Council concerning the Laboratory program and in particular concerning the question whether our effort can be so increased as to make the Super Bomb feasible within the foreseeable future. I should like to present to you my views on this matter in this memorandum. In this way, I hope that more thought can be given to the question before Technical Council convenes.

I would like to outline why it is essential for us to develop a Super Bomb at the earliest possible time or else be able to say with reasonable confidence that the Super is not feasible. The arguments that have led me to this conclusion are of various kinds.

POLITICAL CONSIDERATION: [redacted]

It is my conviction that a peaceful settlement with the Russians is possibl only if we possess overwhelming superiority. We do not now possess such superiority. The most promising prospect to acquire a great lead is by an early development of a Super Bomb. I am sure that such an accomplishment will in itself not solve the problem. Most difficult political questions will also have to be solved. But early possession of the Super Bomb will give us another chance in the political field. Without a Super Bomb such another chance is not likely to arise.

RUSSIAN PROGRESS:

The fact that an atomic explosion took place in Russia at this early a date has considerable significance. It seems that the Russian rate of progress is at least comparable to, if it does not exceed, the rate of progress in this country. The Russians have started working on the atomic bomb approximately in the summer of 1945. They are likely to have given consideration to the problem somewhat earlier but it is hardly probable that the total time of reasonably intensive effort in Russia has exceeded five years. This time is approximately the same as the time that was needed in this country to make and to explode an atomic bomb. Thus the rate of progress in R[redacted] is comparable to the rate at which we have been working during the [redacted] present rate of progress in comparison is far slower than in war[redacted]

It is probable that the Russians did not explore as many po[redacted]es before achieving an atomic explosion as we did. It is also pro[redacted] the Russians have not put into their atomic development th[redacted]horough and elaborate scientific and technical effort as we did. [redacted] therefore claim that their accomplishment is not equal to our wartime a[redacted]omplishment. If this is so, however, it merely proves that the elaborate precautions which we took in our atomic development was not absolutely essential. If the

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Per RR Fredlund Jr. CRD/JRBCRD-0182 Feb 17, 1982
By M. Sandoval FEB 28 1984

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Russians continue to make actual progress faster and if we lose the atomic armament race, it will make little difference whether the reason has been the particular brilliance of Russian scientists or the exaggerated caution and thoroughness of our own group. [redacted]

A detailed possible picture of the Russian progress can be imagined along the following lines:

The Russians probably were familiar with the plans for the Canadian heavy water pile. The captured German scientists also knew of plans for heavy water piles. There are two major technical difficulties in the construction of such a pile. One is the fabrication of metallic uranium. This the Russians have probably learned from the Germans. The other is the production of great quantities of heavy water. There are several ways to accomplish this. One of the best techniques is the distillation of liquid hydrogen. The necessary low temperature technique is quite well developed in Russia. The Russians may therefore have had a pile of the approximate efficiency of the Chalk River pile as early as 1948 or even 1947. The extraction of plutonium from such a pile is a difficult job but can be more easily accomplished if the precautions taken for protection of personnel are less elaborate than those taken in this country. Such precautions are and must be a paramount consideration in our country but the same is not the case in Russia. A pile of the Chalk River type working steadily at 30 megawatts can produce material for a trinity bomb in less than a year. It can produce material for a gun gadget in two years. It is quite possible that the Russians have made a successful implosion. It is also possible, although perhaps somewhat less likely, that they have used the gun assembly and that the actual nuclear explosion was performed with a relatively inefficient gun gadget.

The above description gives the Russians credit for a minimum of scientific and technical progress. Even if this minimum is accepted, further Russian progress can be anticipated along the following lines. The Russians probably will build further heavy water piles. They may also build small piles working with some of the plutonium which the heavy water piles produce. These aims can be rapidly accomplished if no excessive demands are made with respect to high flux, resistance of materials for irradiation or with respect to breeding properties. The Russian rate of production of plutonium may equal the rate of our production within a year and indeed we have no absolute assurance that our production has not been already surpassed. It is therefore not impossible that the Russians should overtake us even in the matter of the stockpile which is the one item which never has been neglected in the United States.

An even more dangerous situation seems to exist with respect to neutron excess. This neutron excess is much greater for heavy water piles than it is for graphite piles and of course even greater for plutonium piles. [redacted] is reasonable to assume that the Russians either are already [redacted] this respect or will be ahead of us in the near future.

The number of available excess neutrons is of [redacted] in several war time applications of atomic energy. [Among [redacted] of tritium is probably the most important since [redacted] is an important component in the production of the Super Bomb.]

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One of the first objectives would be to step up the date on which one can hope to produce a successful booster.

TIME SCHEDULE:

If the Laboratory can marshall the necessary support from Washington for a really vigorous program, the problem of construction and detonating of a Super might be attacked with the same speed with which similar problems were attacked during the war. I realize that this program calls for an all out effort. However, I do not believe that anything less than such an all out effort would be commensurate with the responsibility which this Laboratory has undertaken with respect to the ultimate safety of the nation. It will be essential that all members of the Laboratory contribute fully any ideas they may have how to accomplish the technical details of this job.

[redacted]

[redacted]

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October 1, 1954

THERMONUCLEAR WEAPONS

Period 1946 to January 1950

(Draft version of a section for a history of technical work at Los Alamos since the war)

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(In the following section, the progress of work along a number of specified lines will be traced across this period, and some of the items merely referred to in the present listing will be discussed further.)

May-September, 1946: All the individuals engaged on the studies and calculations discussed at the Conference wind up work underway at that time and prepare final reports, with the exception of Landshoff, who remains at Los Alamos and continues studies of the properties of detonation waves in pure deuterium. (Landshoff remained at this problem until summer, 1947.) From mid July to end of September, Hoyt works on same problem.

September, 1946: Teller proposed the system called the "Alarm Clock," and Richtmyer takes up problem of estimating performance.

October, 1946: Evans takes up study of detonation in deuterium.

November, 1946: LA-610, first Alarm Clock report issued by Richtmyer. Report contains arguments of feasibility in principle, and rough estimates of efficiency and behavior.

December, 1946-January, 1947: Landshoff, Mark and Richtmyer make estimates (embodied in LAMS-560) for use of deuterium (or deuterium and tritium) placed close to the core in a fission bomb test to check predicted features of thermonuclear burning.

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[redacted]

[redacted]

January-February, 1947: Richtmyer starts to develop an improved theory of efficiency of Alarm Clock. Discussion with Teller and von Neumann of possible application of advanced electronic computing equipment (then in early stage of design at Princeton) to Los Alamos problems.

February-March, 1947: Studies of equation of state and related problems, pertaining to thermonuclear as well as fission devices, reactivated at Los Alamos as H. Mayer joins staff. "Monte Carlo" method of computation proposed by Ulam, and LAMS-551, outlining prescription for application of method, prepared by von Neumann, with additional suggestions by Richtmyer.

March-April, 1947: With Teller, planned program for summer, 1947, primary objectives being to: continue studies of detonation in deuterium and Alarm Clock, develop Monte Carlo method, initiate work on obtaining method of calculation of radiation flow in exploding fission bomb, study the proposed experiment to check ideas on thermonuclear burning, and prepare status report on thermonuclear systems. (This last resulted in LA-643, September, 1947.)

May-June, 1947: LA-636: "Improved Theory of the Alarm Clock," issued by Richtmyer.

DoE 63

[redacted]

[redacted]

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July, 1947: Nordheim joined Richtmyer in study of Alarm Clock.

August, 1947: Efficiency calculations for a number of possible Alarm Clock configurations completed with the scheme worked out in LA-636. Landshoff takes up work on radiation flow in fission bomb.

September, 1947: Further Alarm Clock examples calculated (LAMS-625). LA-643[5] issued. [redacted] (As the thermonuclear principles involved in the Booster were not essentially different from those embodied in LAMS-560, consideration of the Booster soon superseded further consideration of the LAMS-560 type of proposal.)

October, 1947: Richtmyer starts to plan a fully-detailed machine calculation of the course of a fission explosion. (This turned out to be a two year program, and the first example was actually calculated only early in 1950.)

December, 1947: Work started separately by Landshoff et al. on simpler and, hopefully, faster fission explosion calculation. (Since Richtmyer's problem came to be known as

---

[5] LA-643: "On the Development of Thermonuclear Bombs." (September 30, 1947.) Written by: E. Teller; Word done by: F. Evans, F. Hoyt, R. Landshoff, M. Mayer, L. Nordheim, R. Richtmyer, E. Teller, E. Zadina.

UNCLASSIFIED [redacted]

[redacted]

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"Hippo," the work by Landshoff was known as "Baby Hippo.") Preliminary consideration given to preparing a detailed calculation of the propagation of burning in deuterium for handling on the electronic computer expected to be completed at Princeton within a couple of years.

January, 1948:

DOE b(3)

(From January through April a considerable amount of effort was required in connection with preparations for the Sandstone tests and consideration of results.)

February, 1948: First automatic machine calculation of Monte Carlo type prepared for handling on the ENIAC. (Monte Carlo calculation techniques were expected to be required in the detailed calculation of deuterium burning, as well as other types of problems.)

March, 1948: Richtmyer (and von Neumann) introduce so-called "viscosity treatment" of shocks, LA-671. (This technique, which was devised to meet needs arising in connection with Hippo, reduced the problem of calculating

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[redacted]

[redacted]

the progress of shock fronts in explosion (and implosion) calculations to manageable proportions on automatic computing machines, and was of profound value in very many of the calculations undertaken subsequently.)

July, 1948: Detailed study begun of behavior of a Booster system (considered either as a test of thermonuclear principles or a possible weapon). Work begun on equation of state of paraffin (wanted in connection with possible experimental gadgets to test ideas in the thermonuclear field).

August, 1948: Study of the scattering of neutrons by light elements to obtain data required in connection with various calculations (Booster, hydrides, and deuterium burning).

September-October, 1948: LA-704, [redacted] Also LA-713, "Further Booster Calculations." These were the first detailed studies relevant to the proposal to test such a device in the tests then scheduled for 1951. [redacted] From this point on, the planning

DoE b(3)

[redacted]

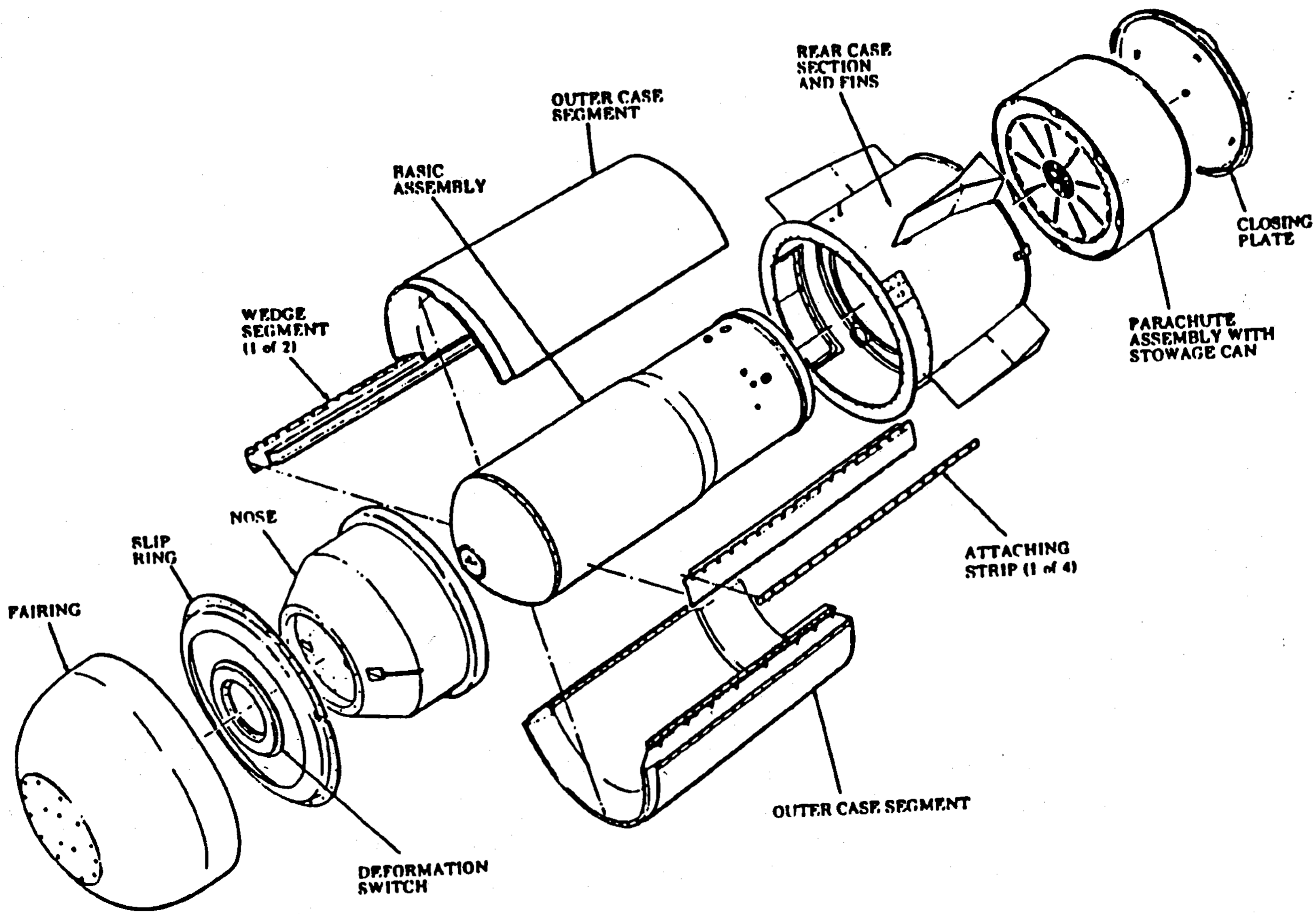

Figure 1 - B53-1 Bomb Exploded View

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WX-1-E-93-410S -1- August 27, 1993

Los Alamos
NATIONAL LABORATORY

Weapon Engineering
WX-1, MS C936
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LOS ALAMOS SOURCE DATA FOR B53 MOD 1

NUCLEAR EXPLOSIVE SAFETY STUDY (U)

BY:

E. D. Aragon, Jr.
B53 Project Leader
GROUP WX-1

Prepared for the DOE/AL B53 NESS to be held at the Pantex Plant on September 28, 1993

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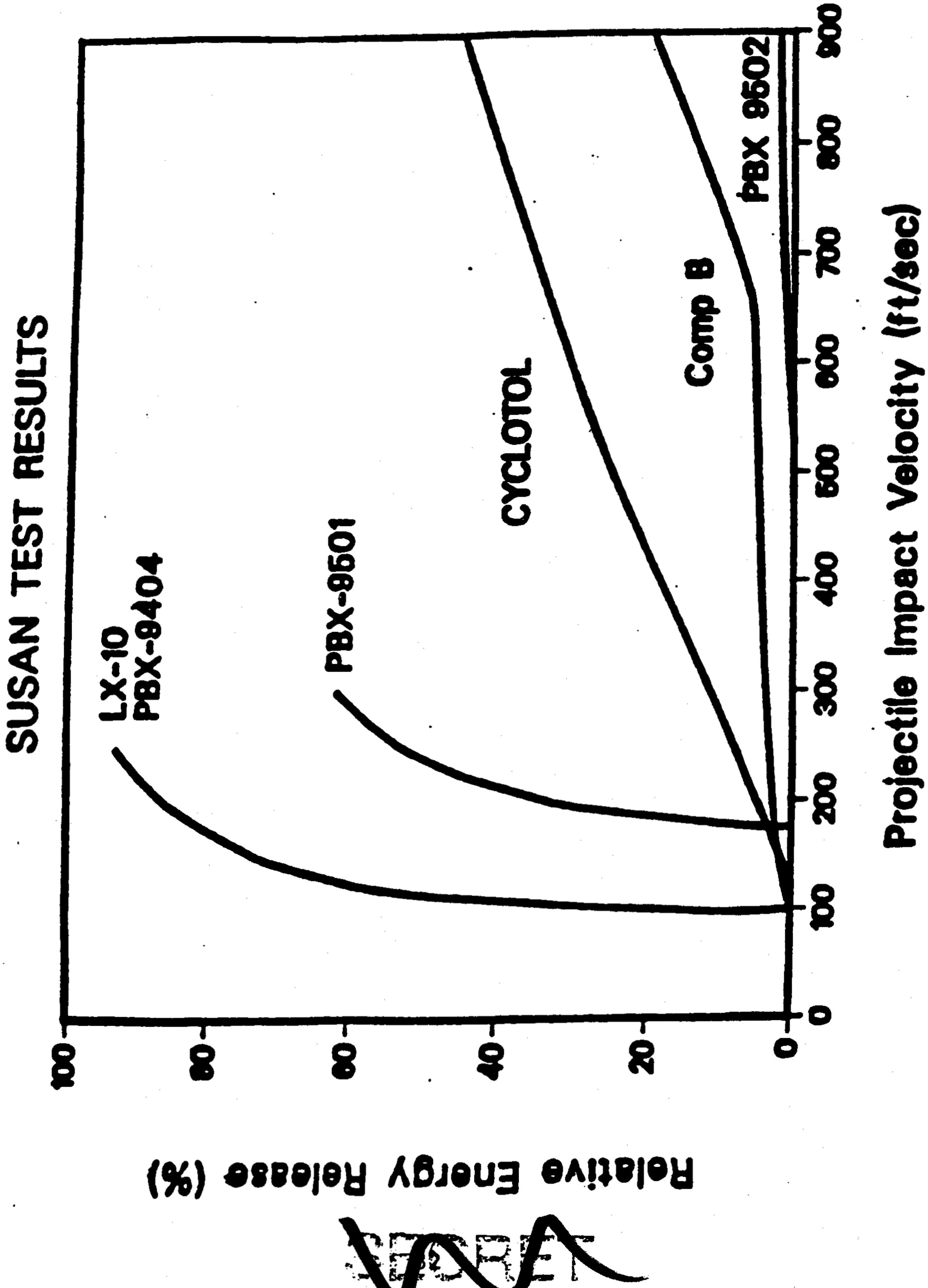

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Fig. 9 - Susan Test Results

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~~Design Information~~
~~DoD Directive 5210.2 Applies~~

A Brief History of the First Efforts of the Livermore Small-Weapons Program (U)

Lawrence S. Germain
January 2, 1991

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LA-11749

January 2, 1991

A Review of the Development of Los Alamos Gnats and Tsetses before the 1958 Test Moratorium (U)

Lawrence S. Germain

(W54/MK54 BASIS)

Nuclear Weapon Data
Sigma 2

Critical Nuclear Weapon
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The Evolution of U.S. Nuclear Weapons Design: Trinity to King (U)

Lawrence S. Germain

January 2, 1991

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DOE b(3)

Thus, at the end of 1949, the stockpile stood at 170 weapons of 4,185 kt cumulative yield. [redacted]

DOE b(3)

The year 1949 was critical because on September 23, 1949, President Truman announced to the nation that the Soviet Union had detonated an atomic bomb. The test was actually conducted on August 9, 1949. As of mid-January 1949, we had 121 nuclear-capable aircraft: 66 B-29s, 38 B-50s, and 17 B-36s.

[redacted]

DOE b(3)

[redacted]

On January 1, 1950, we had 225 nuclear-capable aircraft: 95 B-29s, 96 B-50s, and 34 B-36s. As of July 1, 1950, there were 264 nuclear-capable aircraft, breakdown unknown.

RANGER

Following Sandstone in 1948, no further tests occurred until 1951, when a series of five tests was conducted in 11 days during January and February in Operation Ranger at the Nevada Proving Ground (NPG), later renamed the Nevada Test Site (NTS). [redacted]

DOE b(3)

Because of the short time available, these tests could not be conducted overseas. A portion of the Las Vegas Bombing and Gunnery Range northwest of Las Vegas, Nevada, was selected for the tests. Yields had to be kept small because of possible hazards to surrounding communities. From the time of the concept of Operation Ranger, until its com-

DOE b(3)

DOE b(3)

In spite of the non-unique nature of the stockpile description, a total yield of 49.951 kt with an average yield of about 60 kt has been quoted in the DOE stockpile tabulation.

DOE b(3)

The lightest weight that can be found quoted for these systems either as a bomb or warhead are, 8,170 lb for the Mk-6, 2,405 lb for the Mk-5, 887 lb for the Mk-7, and only 650 lb for the Mk-12, which had not entered the stockpile. Nonetheless, a threshold had been crossed in 1952 with the availability of lighter-weight systems, thereby broadening the spectrum of possible delivery vehicles.

STOCKPILE 1952

DOE b(3)

DOE b(3)

History of the Mk 48 Shell

The predecessor of the Mk 48 Shell was the Mk 33, an 8-inch-diameter, artillery-fired atomic projectile. While this latter shell was still being designed, the Under Secretary of the Army wrote to the United States Atomic Energy Commission, April 28, 1954, expressing interest in the possibility of developing an even smaller diameter projectile with a very low yield, and a broad study was subsequently authorized by the Secretary of Defense May 14, 1954.

The intent of this study was to investigate the possibility of using implosion techniques in an atomic artillery shell, rather than the gun method used in previous shell designs, but the state of the art was not sufficiently well advanced. Much work was, however, accomplished in the ensuing 12 months by the University of California Radiation Laboratory and resulted in a request from the Secretary of Defense to the Atomic Energy Commission, April 4, 1955, for a feasibility study of an 8-inch shell having advanced nuclear techniques. (b)(1), (b)(3)

(b)(3)

Timetable of Mk 48 Events

4/28/54	Army expresses interest in development of small low-yield projectile.
5/14/54	Secretary of Defense authorizes study of implosion-type projectile.
4/4/55	Work by the University of California Radiation Laboratory results in request by the Secretary of Defense for a feasibility study of an 8-inch implosion shell.

(b)(1), (b)(3)

9/20/56	Assistant Secretary of Defense requests United States Atomic Energy Commission to concentrate on atomic artillery shells of 155mm (6.1 inches) diameter.
7/12/57	Assistant Secretary of Defense requests that 155mm atomic implosion projectile be developed.
5/14/58	Developmental guidelines between Atomic Energy Commission and Department of Defense for development of 155mm shell issued.

(b)(1), (b)(3)

8/4/59	Military characteristics approved by the Military Liaison Committee.
11/6/59	Sandia forwards development program definition to AEC.

(b)(1), (b)(3)

3/23/60	Military Liaison Committee suspends higher yield requirement.
1/63	Mk 48 Mod 0 Shell design released.
10/26/63	Early production of Mk 48 Mod 0 Shells.
5/64	Final development report approved and published.

Other components included a corona regulator tube, ceramic spark gap, and an inertial or setback switch. If the tube could not be designed to resist firing shock, other methods of regulation were available that could meet requirements of small size, rugged construction, and dependable operation. An extensive reliability study of the spark gap would have to be made. Due to experience gained on other designs, it was felt that the setback switch would impose no particular problems.[13]

The Army informed Sandia July 16, 1958 that, as the caliber of the implosion shell decreased, the magnitude of the associated engineering problems increased. It was therefore suggested that detailed consideration be limited to the design of a shell with a minimum diameter of 155mm. It was recommended that development engineering be authorized for a shell for the 155mm howitzer and the 175mm gun, but that general small-caliber research be continued.

(b)(1), (b)(3)

In early 1959, reports were received that the Army was planning to cancel requirements for the XW-48. Subsequently, however, the Division of Military Application, in a letter dated April 16, 1959, noted that the Army had again reviewed the program and decided that development work should continue. The Ordnance Department had been directed to provide the Army portion of the shell by July 1962. It was noted that XW-48 military characteristics were being coordinated and would be released in the near future.[16]

Sandia presented a report on the XW-48 firing set to the May 15, 1959 meeting of the Oak Committee. The design was a ferromagnetic transducer type, and formed a right cylinder 3.5 inches in diameter and 1.7 inches high. Tests had been successful, and most design problems had been solved. (b)(3)

The military characteristics were approved by the Military Liaison Committee August 4, 1959, and forwarded to Albuquerque Operations Office. The Division of Military Application, in the transmittal letter, requested notification if any of the requirements could not be met or were objectionable from the standpoint of sound design engineering. (b)(1), (b)(3)

An estimate was requested of the maximum yield that could be expected if no further nuclear tests were conducted.[18]

At this time the length of the projectile was increased 2 inches to create a higher polar moment of inertia. This provided the shell with improved ballistic characteristics, but increased the weight to 120 pounds and reduced the range to 14,000 meters or about 8.5 miles.[19]

Sandia forwarded the XW-48 development program definition to Albuquerque Operations Office November 6, 1959. (b)(1), (b)(3)

subsequently approved and published in May 1964. (b)(1), (b)(3)

It was integrated with a number of components supplied by the Department of the Army to form the XM454, an artillery-fired atomic projectile designed to be fired from 155mm howitzers equipped with either M1A1 or T258 tubes. The maximum range of the projectile was 14,000 meters, or 8.5 miles. The minimum fuze-setting range was 1650 meters, or about 1 mile, which provided safe distance from nuclear detonation. The projectile was 155mm (6.1 inches) in diameter, 34 inches (5.57 calibers) long, and weighed 120 pounds.

(b)(1), (b)(3)

History of the Mk 54 Weapon

FALCON and DAVY CROCKETT Warhead Application

(b)(1), (b)(3)

The FALCON or GAR-11 was an air-to-air missile being engineered by the Hughes Aircraft Company for the Air Force. The DAVY CROCKETT was a ground-to-ground system designed to fire a projectile from a recoilless rifle and was being developed by the Army.[1]

(b)(1), (b)(3)

It was felt that the warhead would be compatible with the DAVY CROCKETT system and be able to withstand the acceleration produced by the recoilless rifle.

(b)(1), (b)(3)

It was felt that production FALCON warheads might be available by February 1961.

Timetable of Mk 54 Events

FALCON and DAVY CROCKETT Warhead Application

1958 Interest develops in lightweight, low-yield warheads for application to FALCON air-to-air missile and DAVY CROCKETT ground-to-ground recoilless rifle.

(b)(1), (b)(3)

1/15/59 Division of Military Application transfers nuclear part of the project to Los Alamos. XW-51 Warhead renamed the XW-54.

10/21/59 Proposed ordnance characteristics of the XW-54 Warhead presented to Special Weapons Development Board and accepted.

12/59 Mk 54 Mod 0 Warhead (FALCON Application) design released.

4/15/60 Mk 54 Mod 1 Warhead design released. This warhead contained no environmental sensing device and was canceled before production.

11/60 Mk 54 Mod 2 (DAVY CROCKETT Application) design released.

4/28/61 Early production of Mk 54 Mod 0 and Mod 2 Warheads.

Special Atomic Demolition Munition (SADM)

2/20/58 Assistant Secretary of Defense notifies United States Atomic Energy Commission that Army has requested feasibility study of an SADM.

(b)(1), (b)(3)

11/10/59 Sandia proposes SADM design to Division of Military Application.

4/7/60 Assistant Secretary of Defense requests Atomic Energy Commission to develop an SADM.

7/26/60 Military characteristics for SADM approved by Military Liaison Committee.

9/5/61 Military characteristics amended to require underwater pressure case.

Mid-1962 Timer development problems cause schedule delays.

(b)(1), (b)(3)

4/63 Mk 54 Mod 1 SADM design released.

8/64 Mk 54 Mod 1 SADM enters stockpile.

6/65 Mk 54 Mod 2 SADM enters stockpile.

Instrumentation errors were discovered on two flights, and aircraft troubles developed on two others, but the rest of the tests were completely successful.[26]

Report SC4632(WD), Final Development Report for the Mk 54 Warhead Systems, was accepted by the Design Review and Acceptance Group December 14, 1961 and forwarded to the Division of Military Application February 19, 1962. The report noted that the warhead was 10.862 inches in diameter, 15.716 inches long, and weighed about 50.9 pounds. The design included a motor-driven chopper-converter system and contained no power supply.

(b)(1), (b)(3)

The electric system consisted of a firing set and detonator assemblies. This system was a standard chopper-converter design largely using off-the-shelf components. It contained no power source, no one-shot devices, and no components requiring field monitoring, although the environmental sensing devices could be monitored.

(b)(1), (b)(3)

These components were interconnected by printed wiring, and the entire assembly was encapsulated in foamed plastic in a fiberglass housing.

Since the fiberglass housing was electrically nonconductive, it was coated with a conductive lacquer to provide an electrostatic shield from warhead connector to rear cap. This coating was requested by the Department of Defense due to the susceptibility of the fuze to radiated electrical noise generated by the firing set. A connector cover and seal were installed on the

warhead connector after the firing set was assembled to the rear cap of the warhead case.

(b)(3)

Environmental sensing devices were placed in the input lines to the converter transformer, and these devices remained open during warhead storage and handling, and closed during a launch environment.

In the Mk 54 Mod O Warhead for the FALCON application, the warhead was installed in the missile section with its longitudinal axis offset about 1/8 inch to allow room for missile cabling. The FALCON was an air-to-air, semi-active radar homing missile, designed to be launched from F-102A aircraft. The missile diameter was 11.4 inches, length 85 inches, wingspan 24.5 inches, and weight 260 pounds at launch and 200 pounds after motor burnout. The rocket motor produced a total impulse of about 12,900 pound-seconds, which applied an acceleration of 20 to 40 g's to the missile, depending on launch conditions. After rocket-motor burnout, the missile tracked the target on a collision course. The guidance system homed the missile on a target that was

either radar-illuminated by the launch aircraft or by electronic countermeasures emitted by the target.

The missile had a proximity fuze with an operating radius of about 100 feet for a 40-square-foot target. The antenna pattern was in a plane perpendicular to the longitudinal axis of the missile. The output of the proximity fuze was connected to the fuze relay through a safing and arming device.

(b)(3)

The warhead power source in the fuze consisted of two 28-volt thermal batteries. The batteries were initiated about 0.5 second prior to launch and came up to voltage about 1 second after initiation. Battery output was applied to the warhead through the safing and arming device at arm time. This device was a switching mechanism that provided warhead arming by connecting the power supply to the warhead connector and preparing the warhead for firing by connecting the proximity fuze to the fuze relay. This latter device provided switch closure between firing capacitors and pulse transformers of the firing set.

The safing and arming device was latched in the SAFE position until about 1.5 seconds prior to launch. The mechanism had two sets of cam-operated contacts. One set, which was normally open, armed the warhead, and the other set, which was normally closed, disabled the warhead after guided flight in the event of a miss. Both sets were committed during launch acceleration after an environment of about 14 g-seconds.

During the drag phase of deceleration, a spring force developed during acceleration drove the switches to the ARM and DISABLE positions through escapement timers. The escapement time depended on the spring force developed during acceleration and on the deceleration experienced by the missile after motor burnout.

(b)(1), (b)(3)

(b)(1), (b)(3)

The arm contacts were spaced to provide warhead power 0.3 to 0.5 second prior to connecting the fuze relay to the proximity fuze.

(b)(1), (b)(3)

The Mk 54 Mod 2 Warhead was designed for the DAVY CROCKETT, the Army's Battle Group Atomic Delivery System. There were two DAVY CROCKETT systems; the XM28, a lightweight, three-man portable system using a 120mm recoilless rifle with a range of 350 to 2000 meters; and the XM29, a vehicle-transported system using a 155mm recoilless rifle with a range from 350 to 4000 meters. Each system fired an XM388 projectile.

The XM388 projectile included the warhead, rear body and fin assembly, and fiberglass windshield. The projectile had a diameter of 11 inches, length of 30 inches, and weight of 76 pounds.

(b)(3)

A manually operated ~~arm/safe~~ switch interrupted the power supply to the warhead when in the SAFE position. The fuze incorporated a mechanical timer to set the time of flight and to provide safe-separation distance. The fuze contained thermal batteries activated at missile launch to supply power to the warhead and squib switches to close warhead firing circuits.

(b)(1), (b)(3)

At launch, the fuze timer mechanism and the inertial switches in the warhead were actuated. Concurrently, the 28-volt thermal batteries in the fuze were activated, and this action started chopper motors in the firing set. When the preset time was reached, four sets of switches in the timer mechanism closed. Closure of two sets of these switches armed the warhead and initiated the X-unit thermal batteries. Closure of the other two sets of switches connected the X-unit thermal batteries to the fuze. Upon sensing

the selected burst height, a set of squib switches closed and triggered the firing set.[23]

Special Atomic Demolition Munition

The Assistant Secretary of Defense notified the United States Atomic Energy Commission, February 20, 1958, that the Army had recently evaluated atomic demolition devices. There was a requirement for a small and light munition that could be carried by one man. This project, which had been initially called the Tactical Atomic Demolition Munition, would be known as the Special Atomic Demolition Munition (SADM), and a feasibility study was authorized.[27]

(b)(1), (b)(3)

The project was delayed while attention was being given to the design of the XW-54 Warhead for FALCON and DAVY CROCKETT applications, although Sandia informed Albuquerque Operations Office, April 23, 1959, that the XW-54 could be considered for SADM application.[6]

Sandia forwarded a proposal for a nuclear demolition munition to the Division of Military Application November 10, 1959. A modified XW-54 Warhead was proposed, containing an integral fuze compactly packaged in a lightweight sealed waterproof housing, and it was suggested that the entire munition be procured and fabricated by the Atomic Energy Commission. The design would provide a rugged munition small enough for covert missions and capable of being rapidly prepared for firing under conditions of high operational stress where time was critical.[30] It was noted that the only existing munition that approached these requirements was the T-4, an adaptation of the Mk 9 gun-type weapon. However, the T-4 was packaged in four 40-pound sections and required four men for delivery. It was felt that an XW-54 SADM would have a diameter of 11-7/8 inches, length of 17-1/2 inches, and weight of 56 pounds including carrying case.[31]

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History of the Mk 56 Warhead

The Mk 56 was a program to provide a thermonuclear warhead for Weapon System WS-133A, whose vehicle was a three-stage, solid-propellant, intercontinental ballistic missile called MINUTEMAN, designed and manufactured by Boeing Airplane Company for the United States Air Force.

The MINUTEMAN missile was a second-generation system with more advanced characteristics than ATLAS and TITAN. A study group had suggested in 1956 that improvements could be made through the use of solid-propellant engines, which would reduce missile size, ground support equipment, numbers of operating personnel, and would increase missile readiness.

(b)(1), (b)(3)

The MINUTEMAN would be about 5-1/2 feet in diameter, 57 feet long, and weigh 65,000 pounds. It would be launched vertically from an unmanned, underground silo-type launcher, and missile stability provided by controlling the rocket nozzle direction.

(b)(1), (b)(3)

Development of the missile was approved by the Department of Defense February 28, 1958, and a study was released March 11, 1958.

This study indicated that two sizes of re-entry vehicles (and nuclear warheads) would be needed to achieve operational flexibility, and the Assistant Secretary of Defense, April 4, 1958, requested the United States Atomic Energy Commission

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to cooperate with the Department of Defense and the Air Force in a feasibility study of two MINUTEMAN warheads, one weighing in the neighborhood of 330 and the other 550 pounds. It was noted that these warheads would be required in large quantities. It was requested that the yields be the maximum achievable in the weights specified and that the systems have an operational deployment date of mid-1962.[1]

The feasibility study group met May 5, 1958 and, having been requested to quickly complete the task, finished the study in one day. It was felt that the lighter device could be developed as a modification of the Mk 50 NIKE ZEUS warhead of the Los Alamos Scientific Laboratory and that a heavier design could be provided by partial rework of the XW-47 POLARIS warhead of the University of California Radiation Laboratory. There appeared to be no unusual interprogram effects concerning application of either design to the MINUTEMAN missile, and it was felt that the operational deployment date could be met.[2]

Little action was taken during much of 1958, due to lack of MINUTEMAN funding.

(b)(1), (b)(3)

Results of this second feasibility study were published March 2, 1959. It was reported that the weight of the XW-47 could be reduced, and that several other Radiation Laboratory designs could be considered for an operational availability date of mid-1963. It was noted that the United States had suspended nuclear testing October 31, 1958 and, as a result, heavy emphasis was placed on designs that could be certified without full-scale test.[3]

The Air Force Special Weapons Center sent a teletype to Sandia March 15, 1959, noting that the Air Staff was considering possible acceleration of the MINUTEMAN

motor. The transformer secondary was connected to storage capacitor and neutron generators through a voltage regulator.

(b)(3)

The warhead could be detonated by either air-burst or surface-burst signal. The signal was produced by the arming/fuzing system and operated a puncture switch, which discharged the storage capacitors through the warhead detonators. Output from this puncture switch also actuated the neutron generators, assuring an ample supply of neutrons at nuclear detonation time.[42]

(b)(1), (b)(3)

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LA-14066-H
History

Tracing the Origins of the W76: 1966–Spring 1973 (U)

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TRACING THE ORIGINS OF THE W76: 1966–SPRING 1973

by

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ABSTRACT (SRD)

The objective in writing this report was to place the development of the W76, before it entered Phase 3, in a historical perspective. The author has rather arbitrarily chosen to consider for this pre-Phase 3 history, the history of the weapon program at Los Alamos during the years 1966–May 1973.

The report tries to provide some understanding as to why, in the spring of 1973, the Los Alamos Scientific Laboratory received the Phase 3 assignment and why the assignment was important to the future of Los Alamos. In addition, the report provides insight into why historically the design of the W76 evolved as it did.

Chapter I provides general information including the organization of the Laboratory during the time-period of interest and the definition of what is included in the different phases in weapon development.

Chapter II discusses the work on primary design.

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CHAPTER I. INTRODUCTION

A. Explanation

1. Assignment

The assignment given to the author was to outline the history of the development of the W76 warhead (presently carried on both the Navy's Trident C4 and D5 submarine-launched ballistic missiles). Because the Los Alamos Scientific Laboratory [LASL] received the Phase 3 assignment for this warhead in the spring of 1973, it would be reasonable to assume that a history of the W76 would cover only the period from the Phase 3 assignment until the initial operational capability of the W76 was achieved in October 1979 (Poseidon back-fit). But history is continuous. What happens at one point in time is dependent upon what happened earlier.

In order to set the development of the W76 in the necessary perspective, give some understanding as to why in the spring of 1973 LASL received the Phase 3 assignment and why the assignment was important to the future of Los Alamos, and indicate several reasons why the design of this device evolved as it did, a history of work prior to 1973 is required. The author has rather arbitrarily chosen to consider for this history, the history of the weapons program at Los Alamos during the years 1966–May 1973. (However, to give continuity, some aspects of the program are also described for work completed before 1966.) This pre-Phase 3 effort at Los Alamos is the focus of this report.

However, the author must insert a warning to the reader. It must be noted that to further increase the complexity that is history, it is almost impossible to identify all the factors that go into determining actions during a specific era. In addition, the description of an event is dependent upon the available "data set" of historical documents. Moreover, how an event is described in a point in time is dependent on what happens later and on our own personal experiences, knowledge, and "mindset." Thus, no history can be completely objective.

2. Overview

Before the award of the design effort for the W76 to Los Alamos, the U.S. nuclear weapon designers had been required—by the introduction of MIRVed (Multiple Independently Targeted Reentry Vehicle) missiles into the U.S. weapon arsenal—to develop lightweight/small warheads for use in the missiles' reentry vehicles.

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Chapter IV will briefly describe the early development effort for several of the materials that would be important in the W76 program.

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The engineering status of several ancillary components such as detonators and gas supply systems will be reported. Chapter IV will also note the vulnerability tests relevant to the LASL XW76 weapon program.

Chapter V will outline and briefly discuss the history of the weapon systems assigned to Los Alamos as Phase 3 programs during the 1966–1972 period. In addition, mention will be made of Phase 1 and 2 programs and early development programs under consideration during those years. This chapter will attempt to inform the reader as to the extensive effort that was required. However, as Chapter V will also describe, the Los Alamos weapon teams failed during 1966-1972 to win a viable Phase 3 assignment to develop a warhead for a strategic missile weapon system. The W62 for the Minuteman III with a Phase 3 of 1964 went to Livermore. The W68 for the Navy's Poseidon submarine with a Phase 3 of 1966 also went to Livermore. Earlier, the W56 (the warhead for the Minuteman I, II) and the W58 (the warhead for the Navy's Polaris) had also gone to Livermore. The Chapter will also note some trends in the U.S. nuclear stockpile that were important for the weapon programs at the Livermore, Sandia, and Los Alamos laboratories.

Although the program was finally canceled, of particular importance to the later W76 development was the Mk 18 program. This program will be covered in some detail in Chapter VI. The Navy's Mk 400 program was the precursor program to the W76. The history of the Mk 400 program will also be outlined in Chapter VI. This chapter will discuss the vital question: who would win the Phase 3 for the Mk 400 (XW76) Los Alamos or Livermore?

B. Los Alamos Scientific Laboratory Management Structure and Philosophy

1. Norris Bradbury

Norris Bradbury served as the director of the Laboratory at Los Alamos from October 1945 until September 1970. When he accepted this job and became director in October 1945 just after the end of WWII, he promised that he would serve for six months. But the six months of service stretched into twenty-five years.

In a January 1967 letter to Charles Winter, Deputy Director of the Division of Military Application, Bradbury described the Laboratory, "Los Alamos is organized on a facility and technology basis; LRL is organized more on a project basis." Bradbury also noted, "Internally in the Laboratory, the weapon program is steered by a committee chaired by the Laboratory Director and comprised of Assistant Directors and relevant Division Leaders. Basic decisions are made by this group, the members of which carry the authority within their respective areas of responsibility to implement them. More detailed discussions and decisions within the framework

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a. Military Requirements for Small, Lightweight Warheads

As noted previously, in the mid-1960s the Los Alamos design group had begun work on 10-inch diameter or less primaries.

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The reason for this great interest on the part of the design laboratories in the 10-inch and less diameter was the fact that the Military was pushing for small, lightweight systems. By this period, the missile/guidance/nose-cone establishment in the United States had developed their systems to where it appeared that it would be possible to put several warheads on one intercontinental ballistic missile (ICBM), deploy the missile, and have each of the warheads hit a different target. This concept is referred to as use of multiple independent reentry vehicles (MIRV). It was felt at that time that the USSR was also going into these types of systems. Because a warhead is much less costly than a missile, the Military wanted to pack as many warheads as possible into each missile. This desire for as many warheads as possible on one missile pushed the nuclear weapon groups to achieve as small as possible in terms of diameter. Moreover, the Military wanted as long a range as possible for each missile; this requirement pushed the weapon groups to try and design minimum-weight warheads.

A request for multiple-carriage capability for the forthcoming improved Minuteman system was formalized in a January 1963 revision to the Phase 1 study. Three reentry vehicles were to be carried in this system—designated the Mk 12 (L). On February 12, 1964, Phase 3 authorization was given for the Mk 12 (L). Livermore and Sandia Corporation, Livermore, were to receive the assignment (the warhead would carry the designation XW62). In November 1964, the Military Characteristics were amended to provide a warhead "compatible with a MIRV application on the advanced Minuteman missile system."[95]

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On August 31, 1964, in a letter to AEC Chairman, Glenn Seaborg, Harold Brown, Director of Defense Research and Engineering, formally proposed the lightweight warhead program. Later, a paper titled "MIRV on Minuteman

[95]Betty L. Perkins, "Tracing the Origins of the Modern Primary: 1952-1970 (U)," Los Alamos National Laboratory report LA-13755-H (SRD) (April 2, 2001), pp. XII-7–XII-14.

and Titan II" and dated March 3, 1965, was provided to the administrations at the weapon-design laboratories.

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3. Reservoir Designs to Provide Minimum Helium in the Boost Gas

In a March 1969 memo, primary designer R. Canada outlined the problems that were the result of the formation of ^{3}He from the decay of the tritium used in the primary's boost gas.

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The yield of a boosted primary is degraded as tritium is converted to ^{3}He both by the loss of the source of 14-MeV neutrons and also by the decrease of the pre-boost multiplication rate caused by the high cross-section for neutron capture which is characteristic of ^{3}He." He went on to add, "In a conventional boosted single-stage device the tritium produced by ^{3}He appears too late in the bomb's explosion to contribute to the yield, and the temperature does not get high enough to produce significant ^{3}He + D fusion."[293]

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[293]R. Canada to Distribution, Subject: "^{3}He in Weapons," W-4-2518 (SRD) (March 10, 1969), 5 pp., A99-019, 199-13.

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C. Vulnerability

1. Considerations

As the USSR began to develop missiles that carried nuclear weapons, military planners in the United States became concerned that these types of weapons could be used as defense weapons against incoming nuclear-armed missiles from the United States. The question then arose as to how to "harden" the U.S. reentry vehicles and warheads to minimize the impact of this type of Soviet defense.

In addition, it became technically possible in the United States to have one missile carry more than one warhead. As these warheads were released and detonated over a target(s), and if the offensive warheads were detonated too close together during a similar time period, the radiation released from one would affect the others. Again, there was the question of how best to deploy these types of warheads and how to "harden" each warhead from the effects of the others (fratricide).

In response to these problems, scientists in the U.S. weapon complex developed special materials and engineering features designed to minimize the damage (both from radiation and from the shock and heat produced by the interaction of radiation with materials) to a nuclear warhead

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~~It was necessary to~~ test these designs and materials to see if they met the design objectives. The tests included field-type tests and tests at NTS. In addition, computer codes were developed, based on experimental data, to predict the behavior of components under adverse conditions.

Several types of field tests were employed. In one type of test, shocks were sent into the special materials to study their behavior. Other tests measured the effects of high temperature and similar adverse environments. In another type of test, radiation from a radioactive source, an accelerator, critical assembly, or reactor was used to expose the device to neutrons or x-rays. The type and amount of radiation that could be delivered was dependent upon the irradiating source. These field tests were never able to duplicate an actual exposure environment during deployment.

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Looking ahead in the period 1973–1980 the number of new systems was even more limited. The ABC program and Mk 18 programs (that evolved into the Mk 400 program) were precursors to the W76; the Phase 3 authorization for this strategic warhead was received by LASL in May 1973. The high-yield multiple RV program/Mk 19/Mk 12A was the precursor for the W78 (Phase 3, June 1974), an assignment that would also go to LASL. The High-Yield bomb program would go to Livermore as the XW77 with a Phase 3 of May 1974. (This program would later become the B83.) The Safeguard (Spartan/Sprint) program would be discontinued. (The weapons that had been stockpiled under this program would be retired.) The improved 8-inch artillery-fired projectile with a Phase 3 date of January 1975 would go to Livermore as the W79. The W80 program, the cruise missile project (air launch, sea launch, and advanced cruise missile) would receive a Phase 3 date of June 1976 and would go to Los Alamos.

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[redacted] The W82, a 155-mm artillery shell, was given to Livermore but was never produced. The W84, the ground-launched cruise missile warhead, would have a Phase 3 of September 1978 and would go to Livermore. The W85 for the Army's Pershing II missile went to LASL (Phase 3 of May 1979), but all warheads would be retired in March 1991 and their components used to build the B61-10 [redacted] (b)(3) The W86, the design for the Pershing II Earth Penetrator, was cancelled after Phase 3.[584] Thus, there were in a sense seven projects in seven years that reached the stockpile.

With few projects being awarded in this time period, it was a tough fight for the Laboratories to procure and complete a Phase 3 assignment.

3. Decreased Levels of Funding

Edward Giller, Assistant General Manger for Military Application, in a TWX dated September 17, 1970, reported to the Laboratories that the low level of FY 1971 on-continent funding as well as the trend being experienced in the overall level of funding meant that less money would have to be spent in the NTS test program than had been spent in previous years. Giller noted, "We must look both at the need for specific tests and test programs and at the way they are conducted. On the need side, we must candidly question such things as total numbers of tests being conducted on similar Phase 2 designs, on effects, or on high yield devices."[585] This was a notice that the NTS test program would need to undergo some changes. Tests would be limited to those considered to be the most important.

Giller continued his warnings to the Laboratories concerning the need to limit spending. In a document dated January 20, 1972, titled "FY-1974 Weapons Program Budget Planning Assumptions," Giller stated, "Any work which does not directly support either present or anticipated future weaponization requirements must be relegated to a lower priority category.

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[584] Betty L. Perkins, "Why Nougat? (U)," Los Alamos National Laboratory report LA-12950-H (SRD) (November 1, 1995), pp. A-1–A-3.

[585] USAEC, Edward B. Giller, Wash., D.C. to BW3, UCLRL, M. M. May, Livermore, Calif., et. al. (OUO) (September 17, 1970), 3 pp., A99-019, 198-12.

7. Yield: The Confetti Argument

Agnew felt that the yield of the W68 was too low to be really effective. In addition, in terms of the overall total yield available from all the W68 warheads, the W68 design was very costly in terms of the amount of required special nuclear materials.

In an April 1972 TWX to Assistant Director for Safety and Liaison (Division of Military Application) Colonel Robert T. Duff, Agnew reported that he was worried about maintaining the U.S. nuclear deterrent. Agnew noted, "It occurs to me that as we go to lower and lower yields in our strategic missile warheads and the Soviet Union builds up a better and better civil defense position, the reality of this deterrent may become questionable.

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If the Soviet leadership believes this, then our strategic deterrent will have lost a good deal of its force. If our MIRV trend continues we'll be threatening to throw confetti at a potential aggressor. Confetti has high penetration and survivability but little deterrent power."[281]

In a letter dated October 10, 1972, to Giller, at that time Assistant General Manager for National Security, Agnew again noted several reasons why low yield warheads might not be the best solution for maximizing the deterrence capability of the stockpile. He reported that considering the number of required submarines and the low efficiency in their use of special nuclear material, the low-yield warheads were not very cost effective. Moreover, Agnew pointed out that for the Hiroshima device, the effects on Hiroshima in terms of loss of substantial buildings and the people in them "wasn't all that impressive." In terms of loss of life, the USSR had lost more than ten million people in WWII. Although the Soviets had an extensive civil-defense network in place, even if that did not work to reduce loss of civilian lives, the Soviets might not mind losing a few people. Agnew wrote, "Again, to me, to continue to increase warhead numbers at the cost of a decrease in yield per warhead could eventually lead to no deterrence in the minds of those we hope to deter." Agnew stated, "I feel very strongly that we should endeavor to convince the DoD that what they should have on the next round is a mix of yields.

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8. Capability

Agnew in his August 10, 1972, letter to Camm pointed out that the Los Alamos group had been developing suitable technology applicable to the new strategic missile warheads. He wrote, "In summary then, we have been working very hard to provide the very latest technology in warhead designs incorporating the most advanced minimum weight hardening techniques to provide an optimum warhead for the next round of strategic missile warheads. In fact, our work has been of such outstanding quality that we have been invited by Admiral Levering Smith to

[281] H. M. Agnew, University of California, Los Alamos Scientific Laboratory, Los Alamos, N.M. to BY3/Colonel Robert T. Duff, USAF, Assistant Director for Safety and Liaison, Division of Military Application USAEC, Wash., D.C. (SRD) (April 14, 1972), pp. 1–2, B11, Drawer 56, Folder 1 of 4.

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